Programmatic Approach
for Preparation of Site-Specific Environmental Radiation Monitoring Plans[1]

1. Introduction

The purpose of this main document is to provide general principles for design of the site-specific environmental radiation monitoring plans (ERMPs) (Annexes 1 through 18 to this document).

The purpose of a site-specific ERMP is to describe the environmental radiation sampling program to detect M101 spotting round depleted uranium (DU) leaving radiation control areas (RCAs). Each ERMP explains, for a specific RCA or set of RCAs, what samples will be taken for those evaluations, where these samples will be taken, how often these samples will be taken, and how these samples will be analyzed for DU.

Figure 1 shows generic environmental pathways (indicated by arrows) that DU could follow from inside an RCA (that is, inside the shaded oval) to outside the RCA (that is. outside the shaded oval). Unshaded rectangles depict media in which DU might be present.

2. Risk Assessment

According to the "standardized Army risk matrix" (US Army 2014a), entry into an area known to contain unexploded ordnance (UXO) involves "high risk."[2] "High risk" means "… high potential for serious injury to personnel … if hazards occur during the mission. This implies that, if a hazardous event occurs, serious consequences will occur. The decision to continue must be weighted carefully against the potential gain to be achieved by continuing this [course of action]" (US Army 2014a).

Entry into a UXO area requires support from explosive ordnance disposal (EOD) personnel.[3] While EOD support mitigates the risk of entry into a UXO area, it does not eliminate the risk.

The "potential gain to be achieved" by collection of environmental radiation samples in a UXO area is knowledge of the concentration of DU in samples of soil, water, air, or biota in the UXO area. However, according to results of RESRAD calculations,[4] it is almost

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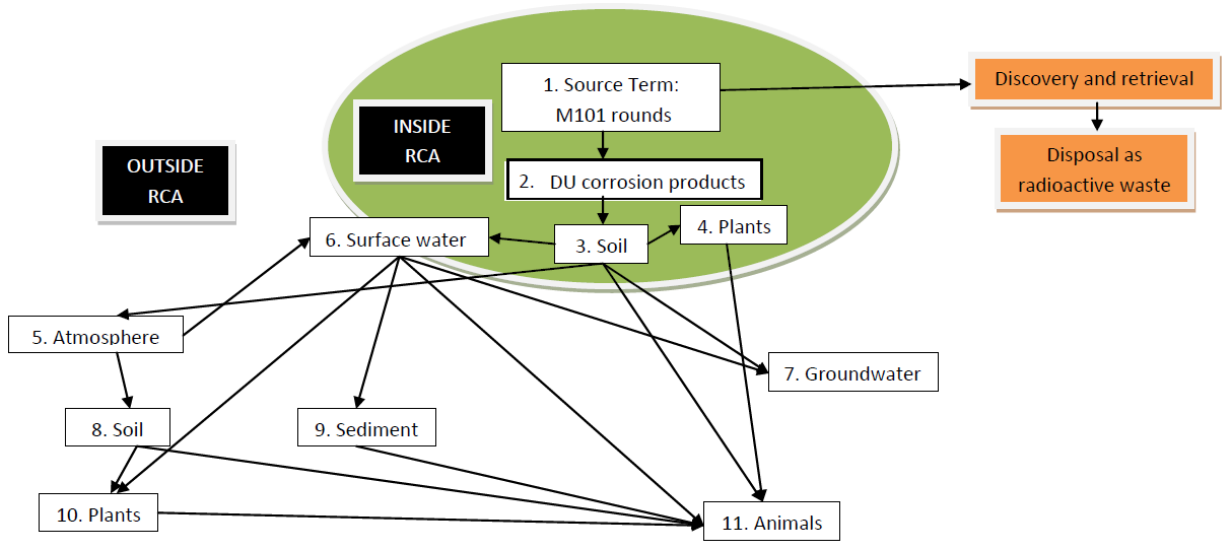
[1] This document supersedes "Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans," dated 18 March 2020 (ADAMS Accession No. Pkg. ML21165A013).

[2] From Table 3-3, Standardized Army risk matrix, in DA PAM 385-30 (US Army 2014a): [*Severity* (expected consequence) = Catastrophic (Death, unacceptable loss …) vs. *Probability* (expected frequency) = Seldom (infrequent occurrences)] → *H* = "high risk."

[3] "Access into temporary and/or dedicated impact areas will be strictly controlled. Those portions of temporary and dedicated impact areas authorized for training or other authorized purposes will be surface cleared of UXO before access is permitted." (US Army 2014b)

[4] See "Bounding Calculations Using RESRAD 7.0 and RESRAD-OFFSITE 3.1" (ADAMS Accession No. Pkg. ML15161A454, Attachment 5 at ADAMS Accession No. ML15161A459).



Pathway	Comment
1→2	Rate of oxidation (corrosion) depends on environmental conditions in RCA
2→3	Oxidized uranium becomes part of soil matrix in immediate vicinity of M101 round in RCA
3→4	Plants in RCA uptake oxidized uranium
3→5	Soil windblown from RCA
3→6	Water flowing through RCA erodes soil and carries it outside RCA, or precipitation dissolves oxidized uranium and carries it to surface water flowing away from RCA
3→7	Precipitation dissolves oxidized uranium and seeps into groundwater
3→11 8→11	Animals ingest soil containing oxidized uranium
4→11 10→11	Animals ingest DU-affected plants (or animals ingest other animals that ingested DU-affected plants) and proceed outside the RCA
5→6	Windblown soil deposits on surface water outside RCA
5→8	Windblown soil deposits on soil outside RCA
6→7	Surface water with dissolved oxidized uranium seeps into groundwater
6→9	Surface water carrying oxidized uranium (in suspended soil or in solution) transfers it to sediment
6→10	Plants outside RCA and adjacent to stream uptake dissolved oxidized uranium
6→11	Animals drink surface water containing dissolved oxidized uranium
8→10	Plants outside RCA uptake soil containing oxidized uranium
9→11	Animals ingest sediment that contains oxidized uranium

Figure 1 Environmental Pathways for M101 depleted uranium leaving a radiation control area

certain that laboratory results from analyses of these samples will indicate DU concentrations (if any DU is detected at all) and implied average annual doses that are far below NRC standards. That is, the potential gain is minimal.

Therefore, collection of environmental radiation samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), garrison safety personnel, and range control personnel, who will advise the garrison commander (that is, they will prepare a formal risk assessment (US Army 2014a)). The garrison commander will then decide whether to allow the collection.

3. Principles

The Army will take samples at each location semiannually in accordance with NUREG-1301 (NRC 1991). Because no guidance exists that is specific to DU in the form of

spent rounds present in the environment, the NRC staff has used NUREG-1301 to inform its review of the Army's proposed sampling methods and frequency (NRC 2018).

Each ERMP will describe how often samples will be taken (semiannual), where samples will be taken, and why those locations were chosen.

Although natural uranium is ubiquitous, DU, which is depleted in uranium isotopes uranium-234 (^{234}U) and uranium-235 (^{235}U) relative to natural uranium, does not occur in nature. Hence, background reference areas and background sampling for DU is unnecessary.

Each ERMP will include the statement (NRC 2018), "When analytical sampling results from locations outside of the RCA indicate that the ^{238}U/^{234}U activity ratio exceeds 3, the Army shall notify NRC within 30 days and collect additional environmental samples within 30 days of the notification of NRC."

Each ERMP will show the distance and direction to the nearest normally occupied areas (for example, residential areas, commercial areas, and business areas) for each RCA at that installation. Each ERMP will provide a description/narrative of the physical environment of each RCA on that installation.

This document cannot address every environmental circumstance at every installation. Site-specific ERMPs should incorporate local information and data. For example, the Army Operational Range Assessment Program (ORAP 2013) has produced environmental data for many ranges.

4. Inside the RCA

Each RCA is within a larger impact area that is part of an Army training area or range facility. Generally, RCAs are open, grassy areas, but young trees and large undergrowth often are present. Minimum distances of RCAs from normally occupied areas outside the training area or range facility depends on the type of munitions used in the large impact areas, but typically are a few kilometers.[5]

Given the purpose of an ERMP, sampling will not usually be performed inside the RCA.

a. M101 spotting rounds

The original source of DU contamination is M101 spotting rounds fired into an impact area, which is now an RCA. Upon impact, these rounds remained intact or mostly intact on or near the surface of the RCA. It is not known for any RCA, except for part of the RCA at Schofield Barracks (Cabrera 2013), whether a cleanup or retrieval of these rounds ever occurred, so the assumption is that most, if not all, of the DU in rounds fired into an RCA remain in the RCA in some form.

[5] For specific information on range safe distances, see DA PAM 385-63 (US Army 2014b).

Any M101 spotting round DU removed from the RCA in accordance with the guidance in the Radiation Safety Plan will be held for proper disposition as radioactive waste.

No conditions require sampling of DU metal alloy in the RCA.

b. Pathway: M101 spotting rounds → DU corrosion products

The rate of corrosion of the DU in the DU-molybdenum alloy in the M101 spotting rounds left in the environment is unknown. A contractor working at Schofield Barracks in 2012 found both contaminated soil and solid DU fragments (Cabrera 2013).

An Army contractor working on the Jefferson Proving Ground (JPG) decommissioning project for DU penetrators consisting of DU-tungsten carbide alloy reported (SAIC 2013):

QUOTE

> Corrosion of DU penetrators and subsequent dissolution of the corrosion products is the primary mechanism for introducing DU into the soil and for subsequent transport to the media (e.g., surface runoff to surface water and sediment). The rates of corrosion and dissolution were determined based on laboratory testing and field observations for conditions similar to those experienced by the DU penetrators at the DU Impact Area. Based on this information, the most likely time to complete corrosion and dissolution of a JPG penetrator was calculated to be approximately 107 years.

UNQUOTE

Although M101 spotting rounds and DU penetrators have geometries and DU alloys that are different from the DU penetrators at JPG, the above observations imply that most M101 spotting rounds have not corroded completely since the Army fired them in the 1960s.

c. DU corrosion products

Corrosion products initially will be on the surfaces of M101 spotting rounds that are then subject to spalling. Sampling of corrosion products in the RCA is unnecessary.

No conditions require sampling of DU corrosion products in the RCA.

d. Pathway: DU corrosion product → Soil

Corrosion products attach loosely to M101 spotting round surfaces. They gradually will leave those surfaces (spalling). Therefore, corrosion products will be present on and near the soil surface in an RCA.

e. Soil

The contractor at JPG observed (SAIC 2013), "… each penetrator or portion thereof served as a point source rather than forming a homogeneous mixture of DU in site soils."

Analysis … of data obtained at Schofield Barracks during a characterization survey (Cabrera 2008a) showed that DU contamination was concentrated in specific locations in the surveyed area and that the rest of the surveyed area was at background concentrations of natural uranium.

An Army contractor reported (Cabrera 2008b), "The mobility and persistence of DU in the environment is influenced by the amount, form, and oxidation state of the metal, as well as by the composition and physicochemical properties of the affected media. In the metal form, DU tends to persist in the soil, and undergo few chemical changes other than oxidation due to weathering and exposure. [Figure 2] illustrates the appearance of Davy Crockett round fragments found at [Schofield Barracks]. Note the oxidized state (bright yellow) of the fragments. … The nature of the underlying soils, coupled with the relatively dry climate favors the retention and reduced solubility of metals, thereby reducing their mobility."

Durante and Pugliese wrote (Durante and Pugliese 2003), "… studies of radiological contamination in the soil from impacted DU rounds [in Bosnia in 1994 and 1995] suggest that dispersion and deposition are localized within 10 m from the hit target."

The Director of the NRC's Office of Nuclear Material Safety and Safeguards wrote, regarding environmental sampling in Vieques, Puerto Rico (NRC 2001):

QUOTE

> From May 29 to June 12, 2000, the U.S. Navy performed radiological surveys of the [Live Impact Area (LIA)]. … The surveys conducted by the U.S. Navy, and independently observed by the NRC, concluded that there

Figure 2 Typical form of DU at Schofield Barracks (Cabrera 2008b)

> were no elevated exposure rates or count rates indicative of radioactive contamination on areas of the LIA exclusive of the North Convoy Site, where the DU was fired during the February 19, 1999, incident. While observing the U.S. Navy survey activities between May 31 and June 12, 2000, the NRC staff also performed numerous surveys and collected soil samples. Soil samples were collected from the areas where DU penetrators had already been excavated. In addition, soil samples were collected downhill of areas known to have been impacted by the DU penetrators. … [A] purpose was … to determine whether the surrounding environment and members of the public had been exposed to DU.
>
> … The NRC Inspection Reports dated July 13, 2000, and September 28, 2000, document the performance and results of the environmental samples taken in June 2000. Copies of these reports are available in ADAMS (ML003767608 and ML003755565). The NRC samples demonstrated that there was no spread of DU contamination to areas outside of the LIA and that contamination from the DU inside the LIA was limited to the soil immediately surrounding the DU penetrators. With the exception of the soil samples taken from holes where the Navy had recovered DU penetrators, neither the direct measurement nor the environmental sample results identified the presence of radioactive materials exceeding those associated with naturally occurring radioactive materials routinely found in the environment.

UNQUOTE

A review of United Nations Environment Programme (UNEP) reports [(UNEP 2001) (UNEP 2002) (UNEP 2003)] (Papastefanou 2002) summarized those reports: “There was no detectable widespread contamination of the ground surface by depleted uranium. This was in such low levels that it cannot be detected or differentiated from the natural uranium existing in soil globally. Detectable ground surface contamination by depleted uranium is limited to areas around and below penetrators and the associated points of concentrated contamination.”

Uyttenhove et al. reported on independent measurements in Kosovo (Uyttenhove, Lemmens and Zizi 2002). They wrote, “Based on our [minimum detectable activity (MDA)]-considerations (and the experimental confirmation with calibration samples), we can state with good confidence that there is no DU present at our 50 sampling points in Kosovo, with MDA values as low as 15 Bq [corresponding approximately to a milligram of DU in a typical sample (100–150 g)]. Some samples, taken near places where DU-ammunitions were used, have been re-examined very carefully with extra long measuring times (27.8 h), always with negative results.”

The Air Force did not find DU outside DU range boundaries at Eglin Air Force Base. As an NRC staffer (Spitzberg 2005) wrote, “The [Air Force] sampled the environs of the site as part of the site characterization process. Radioactive material in excess of the NRC-approved [derived concentration guideline limits] was not identified offsite during … site

characterization studies suggesting that the DU material, a heavy metal, was not migrating outside of the site boundary."

The US Army Environmental Policy Institute wrote (USAEPI 1995), "Investigations of DU migration at U.S. test sites have not identified significant migration in the environment."

An Army contractor that has performed environmental monitoring for DU at JPG for many years has never detected DU in soil or sediment samples outside the DU impact area. Reports dating back to 2005 are available on the NRC ADAMS website.[6]

The US Department of the Army Soldier and Biological Chemical Command (USASSBC) took sediment samples at JPG and reported (USASSBC 2002), "Sediment samples were collected at the same locations where surface water samples were obtained during the scoping survey. The total uranium concentration in sediment samples ranged from 0.88 to 1.09 pCi/g within the DU Impact Area. Along the firing line trajectories, the total uranium concentration in sediment was measured at 2 and 3 pCi/g along two different streams south of the DU Impact Area. The U-238 to U-234 activity ratio in the sediment samples collected during the scoping survey indicates that the uranium is naturally occurring."

Also for JPG in 1995, an Army contractor (Scientific Ecology Group 1995) reported that all results of samples taken in the impact area showed $^{238}U/^{234}U$ ratios less than three.

In 2010, the current License RSO performed an analysis of results in a contractor's characterization survey report for the RCA in the Battle Area Complex at Schofield Barracks (Cabrera 2008a). The results of his analysis showed that unbiased soil samples taken in the RCA contained only natural uranium. The contractor's report showed that biased samples contained both natural uranium and DU. It seems that DU remains close to its point of original deposition in the RCA and is not likely to move outside the RCA in appreciable amounts.

An implication of the above is that M101 spotting round DU does not migrate readily in soil in many, if not almost all, cases. Once it becomes part of the soil matrix, it remains in the same soil matrix for many years.

Generic calculations (Cherry 2012) have shown that if 1000 M101 spotting rounds have completely corroded in a typical RCA (a one-kilometer square) with the corrosion products completely dispersed in the top 15 centimeters of soil, the resulting uranium activity concentration in RCA soil would be about 0.3 picocurie of DU per gram of soil

[6] https://adams-search.nrc.gov/home

(pCi/g).[7] This value is scalable for different RCA areas and different numbers of rounds.[8]

Table 1 is a derivation from Table 3.4 in National Council on Radiation Protection and Measurements (NCRP) Report No. 160 (NCRP 2009):

Table 1 Summary of soil concentration data for uranium

Natural Uranium in Soil	Mean	Median	Standard Deviation	5th Percentile	95th Percentile
Parts per million by weight	1.84	1.81	0.7	0.63	3.1
Activity concentration (pCi U/g soil)[a]	1.25	1.23	0.5	0.43	2.1

[a] Specific activity of natural uranium = 6.77×10^{-7} Ci U/g U

The table shows that the typical natural uranium concentration in soil (about 1.2 pCi/g) is about four times more than the typical DU activity concentration in RCA soil (about 0.3 pCi/g after complete corrosion and distribution in surface soil).

Sampling of soil in the RCA is unnecessary. We expect DU to be in RCA soil.

No conditions require sampling of soil within the RCA.

f. Pathway: Soil → Plants in RCA

The following is an extract from Table 6.4 in Till and Grogan (Whicker and Rood 2008):

Table 2 Typical plant/soil concentration ratios for selected elements and crops, adapted from the International Atomic Energy Agency (IAEA 1994)

Element	Crop	Concentration Ratio (dry mass basis)	
		Expected	Range (95%)
Uranium	Cereal grains	0.001	
	Fruits, tubers	0.01	0.0008 to 0.14
	Grass	0.02	0.002 to 0.2

Some plants, such as lichens, concentrate uranium in their tissues more than most plants do. For example, The USASSBC took vegetation samples at JPG and reported (USASSBC 2002), “Twenty vegetation samples were collected during the scoping survey using the same methods for soil sampling. The USASSBC obtained fourteen samples within the DU Impact Area, and six samples along the firing line trajectories.

[7] According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) the normal concentration of uranium in soil is 300 micrograms per kilogram to 11.7 milligrams/kilogram (0.1 pCi/g to 3.9 pCi/g) (UNSCEAR 1993).
[8] The NRC’s derived default-screening level for decommissioning is 14 pCi DU/g soil (NRC 2006). For the derivation of this value, see “Arguments against Air Sampling during HE Fire into RCAs” [ADAMS ML15151A459].

The total uranium concentration in vegetation samples was less than 0.7 pCi/g in all samples. Two lichen samples from the south-central portion of the DU Impact Area had U-238 to U-234 activity ratios of 2.3 and 2.6, which indicate DU contamination."

The UNEP also detected DU in lichen in the three areas it surveyed [(UNEP 2001) (UNEP 2002) (UNEP 2003)]. According to UNEP, "This indicates that at least some of the penetrators at these sites hit hard targets and surfaces, partly aerosolized into dust, and dispersed into the air" (UNEP 2003). The M101 spotting rounds hit no such hard targets and surfaces, therefore no aerosolization occurred.

The above indicates that expected plant uranium concentrations should be no more than about two percent of the uranium concentration in the soil where the plant is growing, except for plants such as lichens. However, the uranium concentrations in a plant could be as high as about 20 percent of the uranium concentration in the soil where the plant is growing.

g. Plants in RCA

Sampling of plants in the RCA is generally unnecessary.

The Army allows livestock (beef cattle) to graze in an RCA at Fort Hood. RESRAD bounding calculations[4] show that the maximum annual total dose to a resident farmer on the RCA at Fort Hood is about 0.14 millirem. The consumption of meat contributes less than 2 percent of that dose, or less than 0.003 millirem.

The calculations assumed that all meat that the resident farmer consumes derives from livestock grazing only in the RCA. In the case of Fort Hood, the livestock graze over a much larger area that includes the RCA, and consumers of that meat consume meat from numerous other sources. The conclusion is that sampling plants in the RCA will provide little or no useful information.

No conditions require sampling of plants within the RCA.

h. Pathway: Soil → Surface water in the RCA

The most common forms of uranium oxide are U_3O_8 and UO_2. Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of environmental conditions (Argonne National Laboratory n.d.). Triuranium octaoxide (U_3O_8) is the most stable form of uranium oxide and is the form most commonly found in nature. At ambient temperatures, UO_2 will gradually convert to U_3O_8.

i. Surface water in RCA

Sampling of static surface water, such as water in a pond, entirely in the RCA is unnecessary.

No conditions require sampling of surface water within the RCA.

5. Outside the RCA

a. Pathway: Soil → Atmosphere

RESRAD bounding calculations[4] show that the maximum possible ^{238}U air concentration for any site is about 1.3×10^{-4} pCi/m^3. However, the Army has found many M101 spotting rounds on RCAs that seem to be mostly intact with corrosion products in or on the soil in the immediate area adjacent to the round. This means that not all the DU in an RCA is available for suspension into the atmosphere. The expected ^{238}U air concentration due to dust will be much less than the maximum possible value.

For comparison, the NRC effluent standard for ^{238}U in air is 6×10^{-14} µCi/mL = 0.06 pCi/m^3 (NRC 2012), which is more than 450 times greater than the highest possible ^{238}U concentration in air due to DU in the soil.

The NRC did not require the Air Force to perform air sampling during DU remediation at a range at Eglin Air Force Base (Spitzberg 2005): "… perimeter sampling was only required at the discretion of the on-site RSO. The [Air Force] planned to establish environmental controls to prevent erosion, to manage storm water runoff, and to minimize dust emissions. The [Air Force] subsequently discontinued some of these environmental controls because reclamation activities had a minimal impact on the environment."

The NRC has never required the Army to perform air sampling at Jefferson Proving Ground since test operations ceased there in 1995. The NRC source materials license number SUB-1435[9] allows JPG to possess up to 80,000 kg of DU at a single site, which is 14 times greater than the estimated total of all M101 spotting round DU at 16 Army installations.

The Army provided a contractor-prepared report to the NRC (Shia 2005)[10] that said, "The assessments at [Jefferson Proving Ground], [Los Alamos National Laboratory], and [Aberdeen Proving Ground], among other sites indicate that risks associated with potential transport of DU in the air from controlled burns are negligible. The benefit/cost ratio of an air sampling program is extremely low (i.e., the benefits are small and the costs of the program high). Therefore, an air monitoring program is not recommended given the low probability of DU release and transport and the negligible effects on receptors."

The Enewetak Atoll Cleanup Project (1977-1980) was a joint DOD-Department of Energy (DOE) project to remove debris and radioactive contamination (mostly uranium and plutonium, not fission products) from the islands and lagoon of the atoll. Since both are actinides, uranium and plutonium behave similarly in the environment. The DOD operated air samplers whenever contaminated soil movements[11] were underway. The

[9] ADAMS ML073030415
[10] ADAMS ML070090201
[11] "Movements" of Pu-contaminated soil included digging and scraping soil, pushing soil into windrows, loading soil into trucks, dumping soil from trucks into boats, transporting soil to the "storage" island,

report of the project (DNA 1981) concluded, “Throughout the cleanup project, over 760,000 cubic meters of air were sampled on the controlled islands plus more than 211,000 cubic meters at Lojwa. Nearly 5,200 air samplers [sic] filters were analyzed by the lab. No significant airborne radioactivity of any type (including beta) was detected. It is clear from these results – as it was from resuspension experiments performed during early [Radiation Safety Advisory and Inspection Team] visits to the atoll – that the Enewetak contamination situation was not conducive to creation of a resuspension hazard.”

The Environmental Protection Agency (USEPA 2006) says, “The amount of uranium in the air is usually very small and effectively insignificant for remedial operations. … The high density of DU in most particulate forms limits the air transport of DU to relatively small particles. … It is reported that most of the DU dust will be deposited within a distance of 100 meters from the source.”

b. Atmosphere

Air sampling is generally unnecessary. Remedial actions, discussed above and which did not produce significant air concentrations, are not underway at any RCA. In addition, the NRC allowed high explosive testing throughout the JPG impact area, to include the DU impact area, without a requirement for air sampling.

The document, “Arguments against Air Sampling during HE Fire into RCAs”[12] presents four different arguments to demonstrate that air sampling during HE detonations in a DU impact area is unnecessary and likely to be ineffectual.

No conditions require air sampling.

c. Pathway: Soil → Surface water flowing from the RCA

The most common forms of uranium oxide are U_3O_8 and UO_2. Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of environmental conditions (Argonne National Laboratory n.d.). The most stable form of uranium is U_3O_8, which is the form most commonly found in nature. At ambient temperatures, UO_2 will gradually convert to U_3O_8.

d. Pathway: Atmosphere → Surface water

As discussed above, “The amount of uranium in the air is usually very small and effectively insignificant [even] for remedial operations” (USEPA 2006). Therefore, transfer from the atmosphere to surface water outside the RCA is also “effectively insignificant.”

unloading soil from boats into trucks, dumping the soil at a plant for mixing with concrete, and dumping the mixture into a crater for disposal.

[12] ADAMS ML15151A459

e. Pathway: Surface water in RCA → Surface water outside the RCA

The DU concentration in surface water outside the RCA that has flowed from the RCA should be about the same as that the concentration in the flowing water at the RCA boundary.

f. Surface water

The low solubility of uranium in water and the low concentration of DU in soil in the RCA compared to the concentration of natural uranium in soil make it improbable that DU is detectable in surface water. The Army has not detected DU in surface water at any site.[13]

The Army and its contractors sampled surface water extensively at JPG over the last twenty years (SAIC 2013). The amount of DU at JPG is about 73,000 kg, whereas the largest amount of M101 spotting round DU at any one installation is 1843 kg at Fort Benning. Possible detection of DU in surface water at JPG occurred, albeit rarely and always well below NRC effluent limits and USAEPA drinking water standards.

If surface water routinely flows from the RCA, then sampling of this surface water will occur. If flow occurs throughout the year, then sampling will occur every six months. If flow is intermittent, then sampling can occur only when surface water is available.

g. Pathway: Soil → Groundwater

The DU concentration in groundwater depends on several factors, including distance of the groundwater from the soil surface, acidity/alkalinity of the soil and leaching water, soil porosity, amount of precipitation, and so on. The Army has not measured most of the influencing factors for this pathway for any RCA.

h. Pathway: Surface water → Groundwater

The low solubility of uranium oxide in water and the low concentration of DU in soil in the RCA make it improbable that surface water contributions to DU in groundwater are significant.

i. Groundwater

The Army will sample only existing wells potentially influenced by DU in the RCA. The Army will create no new wells solely for the purpose of DU sampling because the cost-benefit ratio is highly unfavorable.

[13] ADAMS ML18136A796 and ML19115A040

The Army will make available for NRC review upon request the results of all Army measurements of uranium concentration in groundwater that the Army made for meeting Safe Drinking Water Act requirements.

If existing wells potentially influenced by DU in the RCA are available, then whenever the Army samples these wells for any purpose, the Army will also require analyses for isotopes of uranium and report the results to the garrison RSO. Otherwise, no conditions require groundwater sampling.

j. Pathway: Atmosphere → Soil

Since the atmosphere is unlikely to carry more than barely detectable amounts of DU from inside to outside the RCA, this pathway will contribute virtually immeasurable amounts of DU to soil outside the RCA.

k. Soil

Soil sampling is generally unnecessary because DU contamination tends to remain in place in the RCA (see paragraph 4e). However, if a local condition indicates that massive erosion of soil from the RCA to areas outside the RCA has occurred, sampling the soil deposited due to that erosion will occur (following risk assessment if UXO is present).

If an area of soil greater than 25 m^2 eroded from an RCA is clearly discernible, then the Army will sample that deposit semiannually with one sample taken per 25 m^2. No other conditions require soil sampling.

l. Pathway: Surface water → Sediment

Water flowing out of the RCA could carry DU-contaminated sediment. Sediment sampling at JPG has occasionally detected small amounts of DU in sediment inside the RCA, but never outside the RCA.

m. Sediment

Waterborne-transport of solids is the most likely mechanism for transferring measurable amounts of DU out of RCAs.

Sediment sampling will occur in streambeds or riverbeds that are down gradient from one or more RCAs.

n. Pathway: Surface water → Plants

The DU concentration in surface water will be low if it is even detectable. However, some plants, such as lichens discussed above, can concentrate DU above ambient levels.

o. Pathway: Soil →Plants

The DU concentration in soil outside the RCA will be much lower than it is in the RCA, if it is even detectable. However, some plants, such as lichens discussed above, can concentrate DU levels.

p. Plants

No condition requires plant sampling.

q. Pathway: Soil → Animals

The DU concentration in soil outside the RCA will be much lower than that in the RCA, if it is even detectable. However, some animals could concentrate DU in their bodies above ambient levels.

The following is an extract from Table 6.8 in Till and Grogan (Whicker and Rood 2008) that demonstrates this possibility:

Table 3 Expected values for transfer coefficients (day/kg^{-1}) in various animal food products (IAEA 1994)[b]

Element	Beef	Pork	Poultry
Uranium	3×10^{-4}	6×10^{-2}	1

[a] The transfer coefficient TC is defined as TC = $C_{prod}(eq)/R$, where $C_{prod}(eq)$ is the measured equilibrium (activity per unit mass) in the product of interest at equilibrium and R is the radionuclide ingestion rate (activity per unit time), in this case the rate of entry into the mouth.
[b] See original source for other data and ranges of values

r. Pathway: Plants in RCA → Animals

Plants that herbivorous and omnivorous animals normally consume do not concentrate uranium above ambient levels, and neither do the herbivorous, carnivorous, and omnivorous animals themselves.

s. Pathway: Surface water → Animals

Depleted uranium concentrations in any water that animals consume are orders of magnitude less than NRC effluent standards and EPA drinking water regulations for uranium. As shown in paragraph 5q, animals generally do not concentrate uranium above ambient levels.

t. Pathway: Soil → Animals

Depleted uranium concentrations in any RCA soil that animals consume are, on the average, less than the default derived concentration guideline limits.[8] The DU

concentration in soil outside the RCA is less than that for soil in the RCA. As shown in paragraph 5q, animals generally do not concentrate uranium above ambient levels.

u. Pathway: Sediment → Animals

Depleted uranium concentrations in any RCA sediments that animals consume are, on the average, less than the default derived concentration guideline limits.[8] The average DU concentration in sediments outside the RCA is less than that for sediments in the RCA. As shown in paragraph 5q, animals generally do not concentrate uranium above ambient levels.

v. Animals

The USASSBC took biological samples at Jefferson Proving Ground and reported (USASSBC 2002), "A total of eight biological samples were collected from deer, freshwater clams, fish, and a soft-shelled turtle. All of the biological samples from Big Creek were collected from the area adjacent to the DU Impact Area. The total uranium concentrations ranged from 0.091 pCi/g in deer liver to a maximum of 0.774 pCi/g in a freshwater clam. … The U-238 to U-234 activity ratio ranged from 0.4 to 1.2 and does not indicate the presence of DU contamination."

An Army contractor working at Jefferson Proving Ground wrote (SAIC 2013), "To evaluate the total effective dose equivalent (TEDE) associated with consumption of deer meat, a total of 132 tissue samples from 30 deer were collected and analyzed during the winter of 2005/2006. DU was not detected in any tissue sample during laboratory analysis."

No conditions require animal sampling.

6. Radiochemistry

Only accredited laboratories will perform radiochemical analyses for the purposes of NRC license compliance. The laboratories will use alpha spectroscopy to analyze samples for ^{234}U and ^{238}U activities and concentrations.

A $^{238}U/^{234}U$ concentration or activity ratio less than 3 indicates natural uranium with little or no DU present, whereas a higher ratio indicates the potential presence of DU (NRC 2018).

All samples with a $^{238}U/^{234}U$ concentration or activity ratio greater than 3 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their ^{235}U and ^{238}U content in an effort to identify samples with DU content.

Annex 19 contains the Programmatic Uniform Federal Policy–Quality Assurance Project Plan (UFP-QAPP).

7. Other requirements

The ERMP or UFP-QAPP will address all other requirements normally associated with environmental sampling (for example, chain-of-custody, health and safety, packaging for shipment, and shipping).

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Annexes

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3. Site-specific ERMP for Fort Bragg
4. Site-specific ERMP for Fort Campbell
5. Site-specific ERMP for Fort Carson
6. Site-specific ERMP for Fort Gordon
7. Site-specific ERMP for Fort Hood
8. Site-specific ERMP for Fort Hunter-Liggett
9. Site-specific ERMP for Fort Jackson
10. Site-specific ERMP for Fort Knox
11. Site-specific ERMP for Fort Polk

12. Site-specific ERMP for Fort Riley
13. Site-specific ERMP for Fort Sill
14. Site-specific ERMP for Joint Base Lewis-McChord
15. Site-specific ERMP for Yakima Training Center
16. Site-specific ERMP for Joint Base McGuire-Dix-Lakehurst
17. Site-specific ERMP for Pohakuloa Training Area
18. Site-specific ERMP for Schofield Barracks
19. Programmatic Uniform Federal Policy–Quality Assurance Project Plan

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN DONNELLY TRAINING AREA, FORT WAINWRIGHT, ALASKA ANNEX 1

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
2405 Gun Shed Road, Fort Sam Houston, Texas 78234-1223

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
BRAC	Base Realignment and Closure Act
CD	Compact Disk
cfm	Cubic Feet per Minute
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
GPS	Global Positioning System
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Donnelly Training Area (TA) in Fort Wainwright, Alaska, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Donnelly TA, Fort Wainwright, Alaska, Annex 1 (ML16265A234) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Donnelly TA. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream **(SWS-01**) from the Georgia Range RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Donnelly TA is a 631,324-acre installation located in interior Alaska, directly south of Delta Junction and 108 miles southeast of Fairbanks (Figure 1-1). The entire installation is operational and includes 124 ranges.

In 1942, an Army Air Corps Base (Station 17) was established at Donnelly TA during World War II, which was deactivated in 1945, reactivated in 1947, and transferred to the Department of the Army. In 1955, the installation was expanded and renamed Fort Greely in honor of Major Adolphus Greely. In 1995, Fort Greely was realigned under the Base Realignment and Closure Act (BRAC). During this time, the operational range area associated with Fort Greely was realigned, renamed Donnelly TA, and is now under the control of U.S. Army Alaska at Fort Wainwright.

The remaining portion of Fort Greely (6,805 acres), adjacent to Donnelly TA, is operated by the U.S. Army Space and Missile Defense Command in support of the Ground Based Midcourse Defense Joint Program Office. In addition to standard personnel training, Fort Greely was and continues to be used by the U.S. Air Force and U.S. Army for cold weather testing and training (EA 2009).

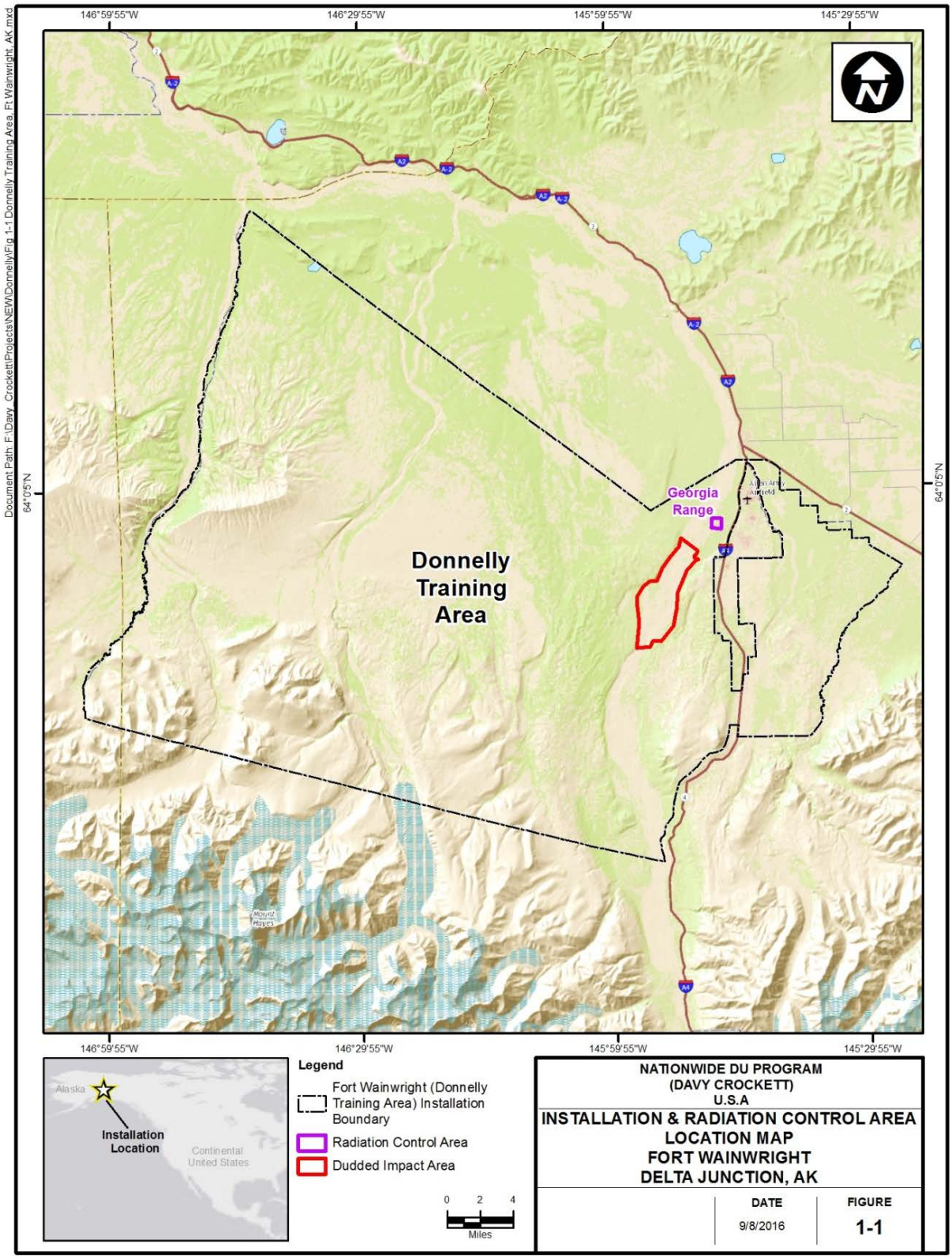

Figure 1-1. Installation and Radiation Control Area Location Map

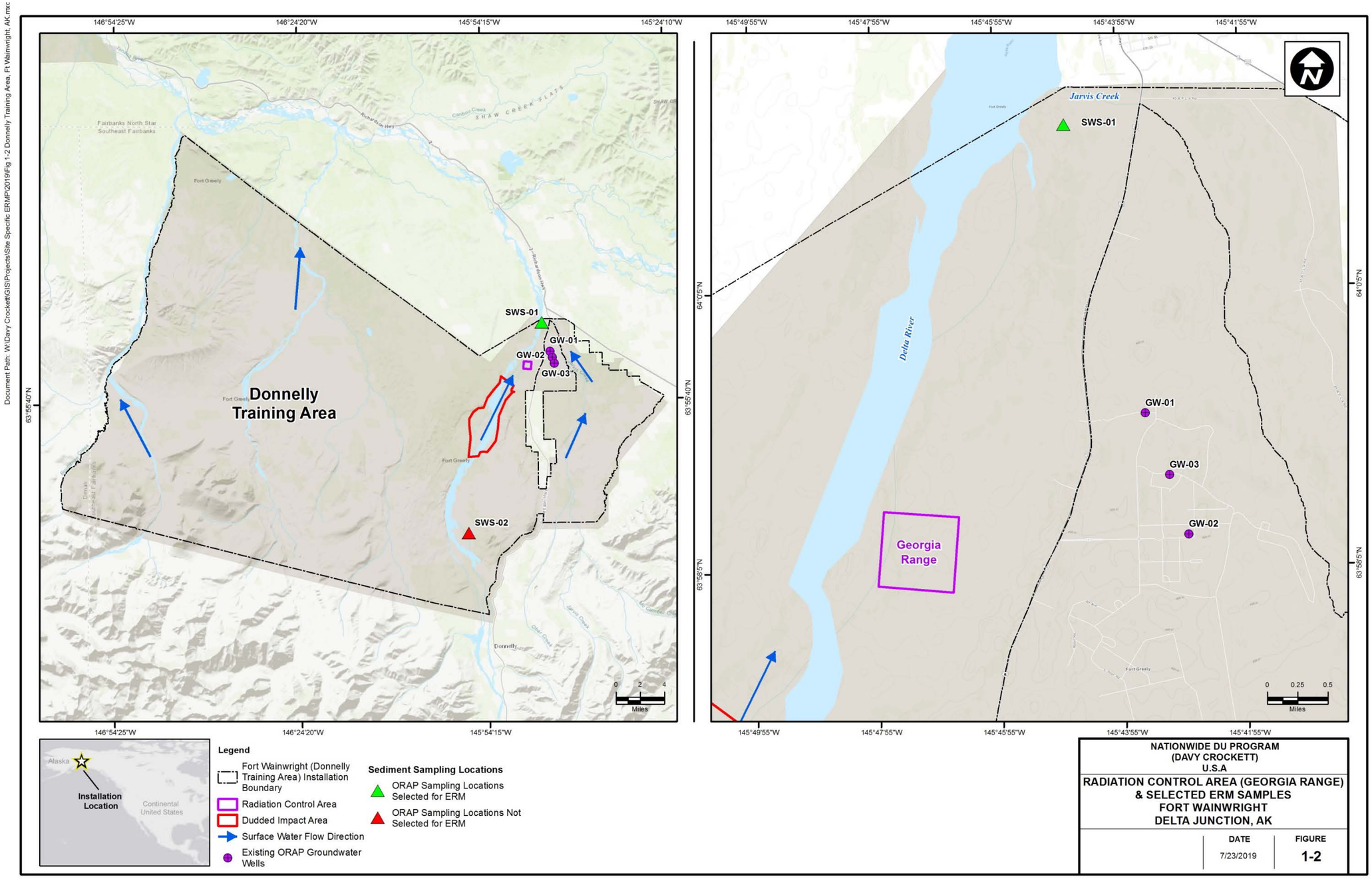

Figure 1-2. Radiation Control Area (Georgia Range) and Selected ERM Samples

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An Archives Search Report (ASR) (USACE 2008) confirmed the presence of one range where the Davy Crockett weapons system was used at Donnelly TA. The historical Davy Crockett surface danger zone (SDZ) consists of 984 acres and was known as the Georgia Range (Figure 1-2). The nearest normally occupied areas to the Georgia Range or radiation control area (RCA) is the firehouse, which is located approximately 1.5 miles east to northeast of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU that was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly TA), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the Georgia Range; therefore, it is assumed that most, if not all, of the 20 kilograms (kg) of DU (SUC-1593) from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Donnelly TA is situated in the Tanana-Kuskokwim Lowland and the northern foothills of the Alaska Range. The installation is bisected by the Delta River and the Richardson Highway, which generally follows the east bank of the Delta River. The topography of the installation is dominated by wide braided river channels of the Delta River, areas of elevated alluvial terraces, and glacial deposits east and west of the Delta River.

The installation is located in the Tanana River Basin, which drains approximately 44,000 square miles. The Tanana River flows northeast and receives discharge from the installation's main drainages. The installation can be divided into five sub-basins that drain northward, including the Little Delta River, Delta Creek, 100 Mile Creek, Delta River, and Jarvis Creek.

The area of the RCA in Donnelly TA is bisected and drained to the north into the Tanana River by the primary channels of the Delta River (Figure 1-2). The Delta River is a braided stream that originates in the Tangle Lakes on the south side of the Alaska Range. Surface water discharge rates measured on the Delta River, 1.8 miles south of Big Delta, indicate flows are highest in July (approximately 10,000 cubic feet per minute [cfm]) and lowest in October (approximately 24 cfm) (USACE 1996).

Groundwater in the vicinity of Donnelly TA is found in the generally highly permeable unconsolidated alluvial and glacial-fluvial sediments. The alluvial aquifer underlying the installation receives recharge from the Delta River and Jarvis Creek. The hydraulic gradient ranges from 0.001 to 0.004. Regionally, groundwater flows in a northeasterly direction from the Alaska Range toward the Tanana and Clearwater Rivers and Clearwater Lake. The water table becomes deeper, farther south, as it approaches the Alaska Range. Near Fort Greely, the water table is approximately 150 to 200 feet below ground surface (bgs) (EA 2009).

The Delta River is a losing surface water feature located in an area surrounding the RCA, which acts to recharge the groundwater system. Groundwater recharge is highly dependent upon the river conditions, which vary seasonally in accordance with freeze-thaw cycles. Water levels in installation wells, located near the Delta River, fluctuate in direct response to changes in seasonal recharge to the alluvial aquifer from river and stream channel losses, and precipitation. The rise in river level has been correlated with a staggered rise in groundwater level, indicating that the river and aquifer are hydraulically connected. Groundwater level fluctuation has been approximately 20 feet per year in the installation cantonment area. Typically, groundwater levels are their lowest in late May to early June (when recharge begins) and at their peak in September to October (when recharge ceases), in connection with the river ice break-up (snow melt) and the refreezing of the river, respectively.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the Georgia Range at Donnelly TA are as follows:

- ***Surface Water Use***—No known use of surface water exists for consumption of drinking water downstream from Donnelly TA.
- ***Recreational Use***—There are no designated recreational use areas within 15 miles downstream from the installation. Fishing is limited downstream from the installation on the Delta River, Delta Creek, and Little Delta River due to the braided stream channels and silt- laden waters. Although human receptors are identified in the U.S. Army Operational Range Assessment Program (ORAP) Phase I assessment as being exposed via the food chain from off-range recreational fishing, evidence suggests that the limited uptake and bioaccumulation of metals, explosives, and perchlorate in fin fish do not pose a risk to humans when consumed at the recreational level.
- ***Sensitive Environments***—Sensitive environments on and around Donnelly TA include wetlands and watercourses designated as important for anadromous fish species.
- ***Habitat***—Approximately 68 percent of Donnelly TA is classified as wetland or open water. The most common wetland types include alpine tussock meadow and alpine wet low scrub, lowland wet low scrub and lowland tussock scrub bog, lowland wet forests, and riverine and lacustrine wetland complexes. The Tanana River is considered an important waterway for the spawning, rearing, and migration of anadromous fish species, which is within 15 miles downstream.
- ***Ecological Receptors***—There are currently no federally listed or state-listed threatened or endangered species identified on or around Donnelly TA. The Tanana River system is recognized as a critical habitat for anadromous Chinook and Chum salmon. Anadromous salmon spend periods of their lives in both saltwater and freshwater and utilize the river system for transit, rearing, and spawning.
- ***Groundwater Use***—Groundwater within 4 miles downgradient from the installation is used for public and private drinking water supply. There are numerous community and private wells surrounding Donnelly TA that rely on drinking water from the shallow unconsolidated alluvial aquifer. In addition, several potable drinking water wells, located downgradient from the installation, are utilized by Fort Greely.

Potential human receptors include those within Fort Greely and near Delta Junction relying on potential public and private wells within 4 miles downgradient from the RCA for potable water. Ecological receptors include sensitive environments (e.g., wetlands and anadromous fish habitat).

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Georgia Range at Donnelly TA are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of one sample from a location downstream from the RCA near the property boundary of the Donnelly TA (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling location at Donnelly TA was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-01***—The selected sampling point is located on the Delta River, downstream from the RCA at the installation's northern boundary and upstream of the confluence between the Delta River and Jarvis Creek. SWS-01 allows for relatively easy access and is located on the east river bank. It is located at the foot of an access road just south of Jarvis Creek.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238/uranium-234 (U-238/U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

Donnelly TA lies in a region with a subarctic climate that may prevent sampling on the PAERMP's specified semiannual interval. Due to Donnelly TA's unique weather conditions, including the existence of snow and ice accumulations greater than the national average (and subsequent flow in streams associated with spring thaw), samples will be collected every 6 months, if possible, depending on weather (e.g., time periods when streams are not frozen).

The selected downstream sampling location, SWS-01, for the environmental radiation monitoring (ERM) and the upstream reference location, SWS-02, were sampled during the ORAP Phase II assessment in 2012 and analyzed for uranium in surface water and sediment (U.S. Army 2014). The range of U-238/U-234 activity ratios from the May, June, and September 2012 sampling events is presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Downstream (SWS-01)	4	0.70-1.63
Reference (SWS-02)	4	0.53-0.98

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Downstream (SWS-01)	3	0.93-1.26
Reference (SWS-02)	3	0.82-0.91

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Donnelly TA, Fort Wainwright, Alaska, Annex 1 (ML16265A234) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, SWS-01, in 2017 and 2018 when weather and/or site conditions permitted. The concentrations of total and isotopic uranium in sediment from the ERM sampling events at Donnelly TA are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01*	5/25/2017	0.59 +/- 0.31
SWS-01	8/30/2017	0.11 +/- 0.03
SWS-01	6/5/2018	0.92 +/- 0.33
SWS-01	9/13/2018	0.88 +/- 0.39

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01	5/25/2017	1.1 +/- 0.3
SWS-01	8/30/2017	0.97 +/- 0.24
SWS-01	6/5/2018	1.1 +/- 0.3
SWS-01	9/13/2018	1.0 +/- 0.2

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Donnelly TA.

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment in June 2012 were analyzed for uranium (U.S. Army 2014). The results of the June 2012 sampling event are presented in Table 2-5. The existing groundwater monitoring wells are shown in Figure 1-2.

Table 2-5. U-238/U-234 Activity Ratios for Groundwater Samples

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)*
GW-01	2 (includes duplicate)	0.70-1.04
GW-02	1	1.36

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU.

Presently, no groundwater monitoring wells are located at or near the RCA. In addition, groundwater in the shallowest aquifer flows toward the river and the RCA is located on the river. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Donnelly TA.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Donnelly TA does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Donnelly TA will be coordinated with the Fort Wainwright Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (i.e., 20 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Donnelly TA RCA

Parameter		Default Value	Donnelly TA Georgia Range	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	1.97×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC Materials License = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	1.8×10^{-4}	
	U-238	N/A	0.03	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 178 to 260 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand (Soil is loamy sand from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	8.1	**www.usa.com** for Fort Wainwright, AK
Precipitation rate (annual rainfall) (m/y)		1.0	0.35	**www.usa.com** for Fort Wainwright, AK
Saturated Zone				
Saturated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone				
Unsaturated zone 1, thickness (m)		4.0	54	Depth to groundwater is generally 178 to 260 ft bgs
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Donnelly TA RCA

RCA Layout Parameter	Donnelly TA Georgia Range			
Distance to nearest normally occupied area (m)	3,200			
Bearing of X axis (degrees)	180 (east)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate		Y Coordinate	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	4300	4332
Leafy vegetables plot	500	531.25	4334	4366
Pasture, silage growing area	500	600	4516	4616
Grain fields	500	600	4366	4466
Dwelling site	500	531.25	4200	4232
Surface-water body	500	800	4616	4916
Atmospheric Transport Parameter				
Meteorological STAR file*	WA_SPOKANE.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow)	3,200			
Distance to surface water body (SWB) (parallel to aquifer flow)	3,616			
Distance to well (perpendicular to aquifer flow)	0			
Distance to right edge of SWB (perpendicular to aquifer flow)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow)	150			
Anticlockwise angle from x axis to direction of aquifer flow	0			

* RESRAD Offsite has no meteorological STAR files for Alaska or Hawaii. The selected STAR file is based on nearest available location. The inhalation pathway dose is insignificant to external and groundwater dose pathways.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Donnelly TA does not exceed 1.0×10^{-2} milliSievert per year(mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Donnelly Training Area Georgia Range	3.5×10^{-3}	1.6×10^{-3}

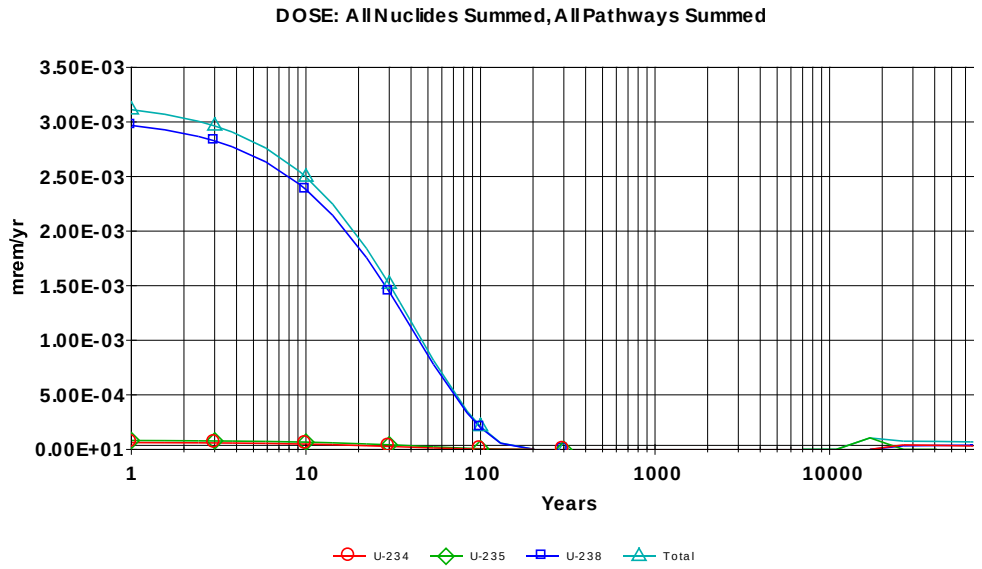
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

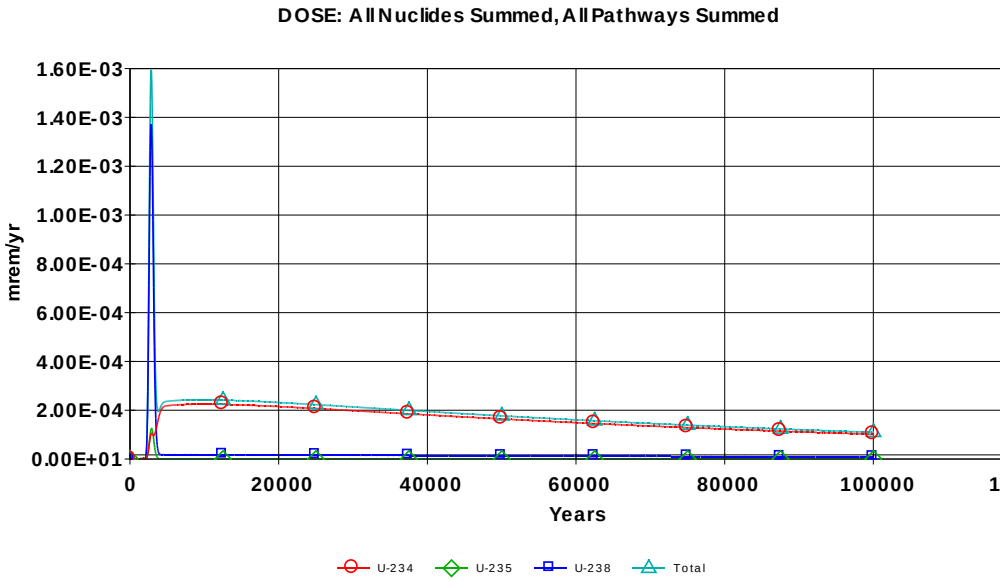
Figure 4-1. Residential Farmer Receptor Dose Graphs

Donnelly Training Area Georgia Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ = 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT MOORE, GEORGIA ANNEX 2

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
2405 Gun Shed Road, Fort Sam Houston, Texas 78234-1223

Submitted To:

U.S. NUCLEAR REGULATORY COMMISSION
Office of Nuclear Material Safety and Safeguards
11545 Rockville Pike, Two White Flint North, Rockville, Maryland 20852-2738

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
DZ	Drop Zone
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
GADNR	Georgia Department of Natural Resources
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
PAL	Project Action Level
PCB	Polychlorinated Biphenyl
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
TMDL	Total Maximum Daily Load
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
USACE	U.S. Army Corps of Engineers
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to U.S. Army Installation Fort Moore in Fort Moore, Georgia, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Benning, Georgia, Annex 2 (ML21165A013) (U.S. Army 2020a) and documents the Installation name change from Fort Benning, Georgia, to Fort Moore, Georgia, on May 11, 2023.

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Moore. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream (**UC2**) from the K-18 Range (Cactus OP) and K-15 Range/Concord OP/DUD Area RCAs, and (**OC2**) from the Hook Range, Buchanan Range, Coolidge Range, Patton Range, Z-4 (Lae Range), and Burma Hill Range (Demo Area) RCAs, as shown in Figures 1-2 and 1-3 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Moore is approximately 182,000 contiguous acres that span between Muscogee, Chattahoochee, and Russell Counties (Figure 1-1). About 93 percent of the installation is in Georgia, with the remaining portion located in Russell County, Alabama. Fort Moore land is used for military training (e.g., ranges, drop zones [DZs], and landing zones), military administration, and land management activities (Arcadis 2011). The terrain at Fort Moore provides a challenging, realistic training environment for all soldiers who train there. Fort Moore's primary missions are to provide the world's best infantry soldiers and trained units and serve as a power projection platform capable of deploying and redeploying soldiers and units anywhere in the world on short notice (Arcadis 2012). In 2023, Fort Benning was renamed Fort Moore.

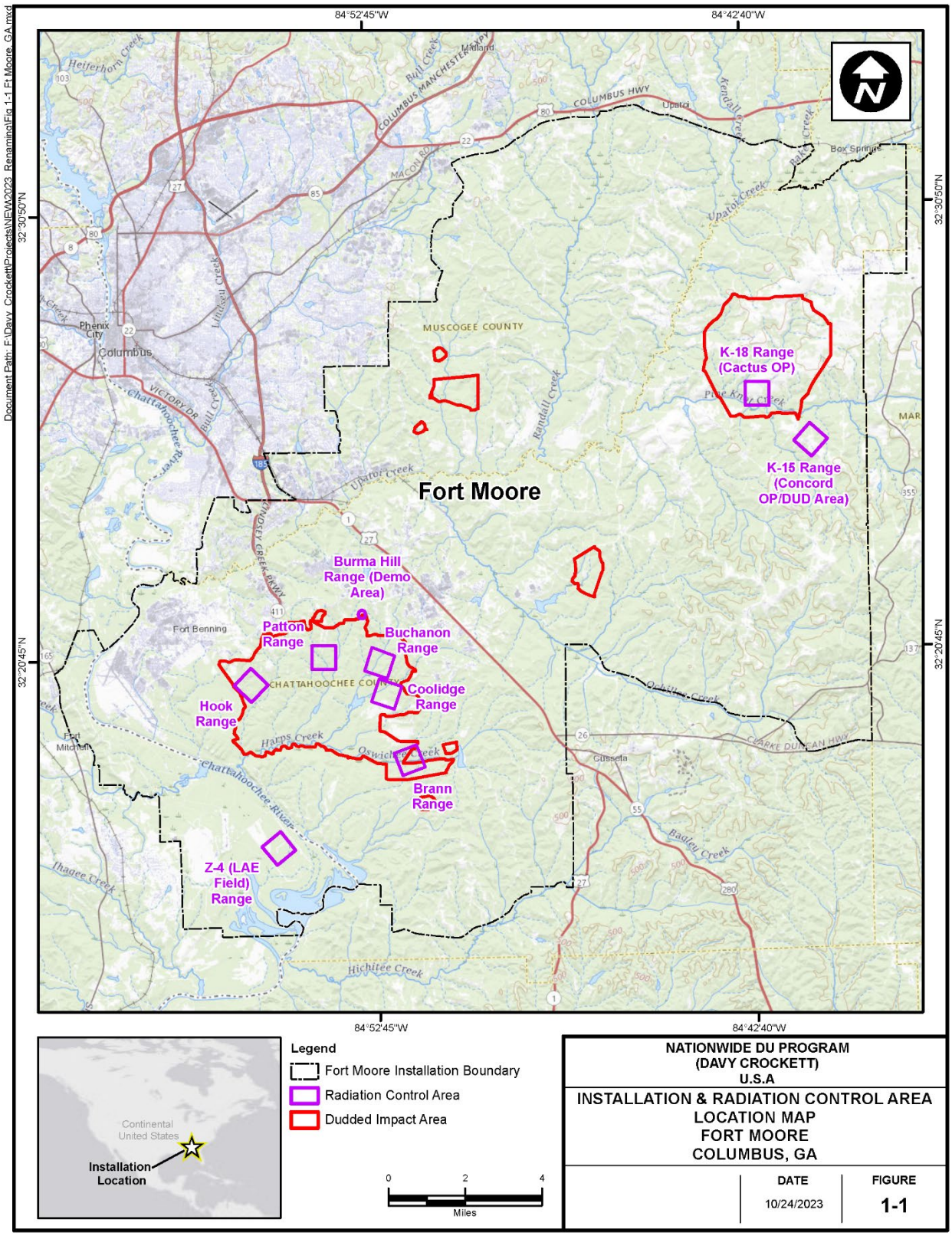

Figure 1-1. Installation and Radiation Control Area Location Map

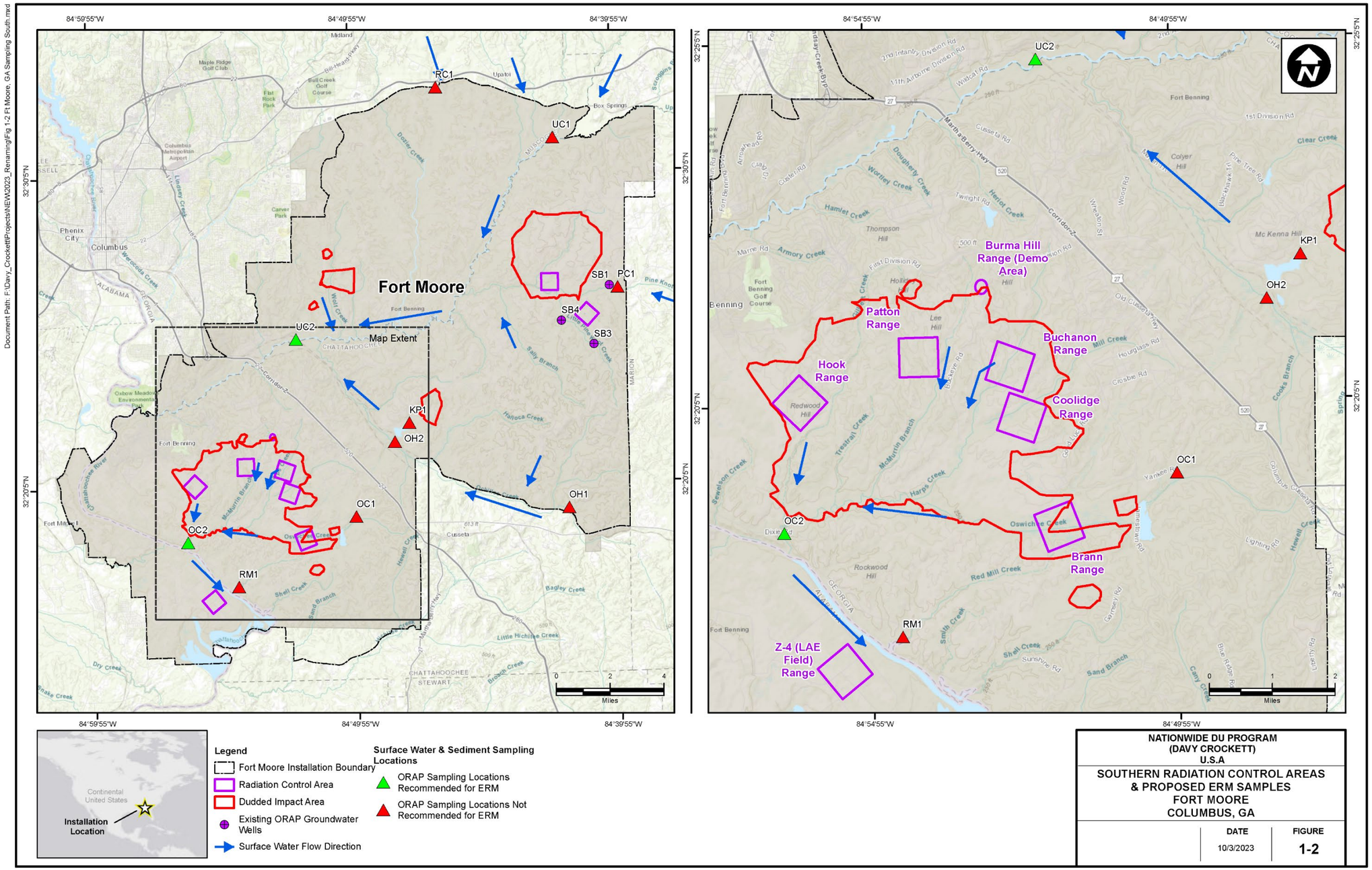

Figure 1-2. Southern Radiation Control Areas and Selected ERM Samples

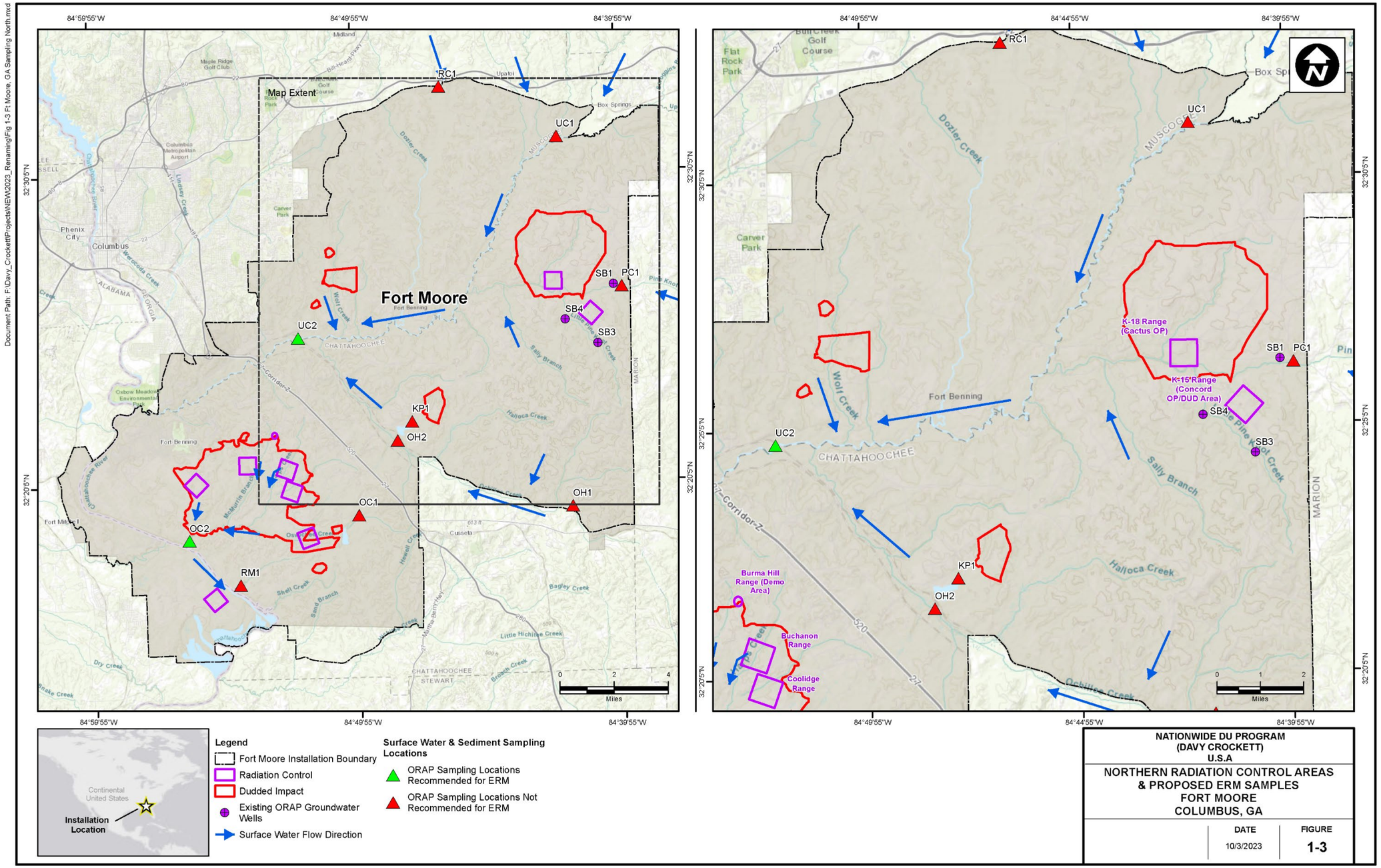

Figure 1-3. Northern Radiation Control Areas and Selected ERM Samples

Of the 182,000 acres, 141,471 acres (approximately 78 percent of the total land area) are designated for training. The training areas (TAs) consist of 48,171 acres of light maneuver area primarily in the southwestern portion of the installation; 62,958 acres of heavy maneuver area primarily in the northeastern portion of the installation; and 30,342 acres of Nondudded Impact Area. There are also 15,554 acres (9 percent) of permanently Dudded Impact Area. The Dudded and Nondudded Impact Areas are concentrated in the northeastern corner of Fort Moore (Kilo Range Complex), the southern portion (Alpha Range Complex), and near the western installation boundary (Malone Range Complex). US-27/280 divides the northeastern and southwestern sections of Fort Moore.

An Archives Search Report (ASR) (USACE 2008) documented the following eight ranges where the use of the Davy Crockett weapons system is suspected based on historical documentation or confirmed based on physical evidence (i.e., Davy Crockett components or debris) observed during the site inspection:

- Hook Range
- Buchanan Range
- Coolidge Range
- Patton Range
- Z-4 (Lae Range)
- K-18 (Cactus OP)
- K-15 (Concord OP/DUD Area)
- Burma Hill Range (Demo Area).

The ASR concluded demolition operations of the Davy Crockett ammunition is suspected at one range (i.e., Burma Hill Range [Demo Area]) rather than the artillery training activities. Subsequent to the ASR, the Davy Crockett weapons system is suspected of being used at one additional range, the Brann Range. The locations of the impact areas for the nine ranges or radiation control areas (RCAs) for Fort Moore are presented in Figures 1-2 and 1-3. The nearest normally occupied areas to each of the nine RCAs are presented in Table 1-2.

Table 1-2. Summary of Distances to Occupied Buildings

RCA	Occupied Building	Approximate Distance and Direction
Hook Range	Pool Range	0.65 miles (northwest)
Buchanan Range	Buchanan Shoot House	0.60 miles (northeast)
Coolidge Range	Coolidge Left Range	0.30 miles (southeast)
Brann Range	Galloway Range	0.36 miles (north)
Patton Range	Patton Range	0.52 miles (north)
Z-4 (Lae Range)	Griswold Range	0.83 miles (northeast)
K-18 (Cactus OP)	Hartell OP	0.43 miles (southwest)
K-15 (Concord OP/DUD Area)	Ranger Objective	0.25 miles (northwest)
Burma Hill Range (Demo Area)	Porter Range	0.27 miles (northeast)

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode.

Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly TA), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Fort Moore; therefore, it is assumed that most, if not all, of the 1,850 kilograms (kg) of DU (SUC-1593) from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Fort Moore is located in an area characterized by a warm and humid, temperate climate. Average annual precipitation in the area of Fort Moore, primarily rainfall, is approximately 45 to 55 inches per year (Arcadis 2011). Fort Moore lies within the Coastal Plain Physiographic Province of central Georgia and Alabama. It is underlain mostly by Mesozoic, Cretaceous sedimentary rocks from the Bluffton and Tuscaloosa Formations. Floodplains are general undifferentiated stream alluvium from terrace deposits. No major regional structures are on the installation. The closest, the Goat Rock Regional Fault Line, is approximately 15 miles north of the installation in northern Muscogee County and southern Harris County. This area represents the fall line running through much of central Georgia (NRCS 2008).

The rivers and streams are primarily characterized as perennial and free flowing. The streams located in the northern portion of the installation generally flow in a southerly direction on Fort Moore, while streams in the southern portion of Fort Moore generally flow from east to west on the Georgia side and west to east on the Alabama side of the installation. Ultimately, the surface water drains toward the Chattahoochee River, which designates the state line between Georgia and Alabama. The Chattahoochee River dominates the surface water flow regime at Fort Moore.

Three surface water watersheds are at Fort Moore: the Upatoi Creek, the Red Mill Creek, and Oswichee Creek (Arcadis 2011). The watersheds of the Oswichee Creek and Red Mill Creek, both tributaries to the Chattachoochee River, drain the majority of the southern portion of the installation, including the RCAs located in the southern portion of Fort Moore. The Chattachoochee River flows through the southwestern portion of Fort Moore and forms the border between Georgia and Alabama. Several low order streams drain the installation and flow directly into the Chattachoochee River. The Oswichee and Red Mill Creeks are the two largest tributaries. The Upatoi Creek watershed drains 116,448 acres and includes nearly 70 percent of the operational range area on Fort Moore. The watershed is located in the northern portion of the installation and drains southwesterly into the Chattahoochee River. Kings Pond and Ochillee Creek are located within the Upatoi Creek watershed.

Shallow groundwater in the vicinity of Fort Moore is described as mimicking the ground surface topography with shallow groundwater flowing from areas underlying hilltops or ridges to low-lying areas or streams (Arcadis 2011). Shallow groundwater interaction with surface water is prevalent; however, there is potential for shallow groundwater interaction with deep aquifers. The majority of precipitation that infiltrates through soil enters the shallow flow system and discharges to adjacent streams. Several areas on installation are underlain by substantial clay layers that may inhibit downward migration of groundwater. These layers likely promote lateral movement of groundwater as interflow and the discharge of this groundwater to the surface water.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCAs at Fort Moore are as follows:

- ***Surface Water Use***—Once the surface water is outside of the installation boundaries, human receptors can interact with surface water and sediment via ingestion (incidental during recreational use and through surface water intakes for potable use), dermal contact, and/or ingestion of fish.

  The Chattahoochee River passes through the installation along the Georgia and Alabama state line. In some areas, the Chattahoochee River is completely surrounded by operational range activity; however, the Chattahoochee River is considered off-range along the entire flow path (Arcadis 2011). The State of Georgia has designated fishing as the sole beneficial use of the Chattahoochee River from Upatoi Creek to the Chattahoochee and Stewart County line at the southern boundary of the installation (GADNR EPD 2010); however, the construction of a surface water intake in the Chattahoochee River will likely add potable water source as a beneficial use. The Chattahoochee River, in this reach, is in violation of the beneficial use standards due to elevated fecal coliform levels potentially caused by urban runoff. Downstream from the installation, the Chattahoochee River has been impounded near Fort Gaines, Georgia, to create Lake Walter F. George, a U.S. Army Corps of Engineers (USACE)-managed recreation resource. Lake W.F. George supports the beneficial use of recreation (GADNR EPD 2010). No violations are currently listed; however, a total maximum daily load (TMDL) assessment was completed for Lake W.F. George and a TMDL has been established for polychlorinated biphenyls (PCBs).

  The Chattahoochee River and Lake W.F. George can be accessed at multiple points for fishing, boating, and swimming. The most upstream access point that is off-range is the Uchee Creek Army Campground, which has a boat ramp and is located within the boundaries of the installation at the confluence of Uchee Creek and the Chattahoochee River in Alabama. Off-installation residents and recreational users of the Chattahoochee River and Lake W.F. George may also gain access at several locations downstream from the installation. River Bend Park is a day use area with a boat ramp and is located on the Chattahoochee River immediately downstream from the installation. Bluff Creek Access Area is approximately 9 miles downstream from the installation. Bluff Creek has a campground and boat ramp. Hatchechubbee Creek Park is 13 miles downstream from the installation and provides camping and a boat ramp to recreational users. Florence Marina State Park is the first recreational area downstream from the installation (approximately 16.5 miles downstream) that officially offers a swimming area, although swimming may occur at other designated and nondesignated recreational areas upstream of the state park. Florence Marina State Park also offers camping, a fishing pier, and a boat ramp to recreational users. The Georgia Department of Natural Resources (GADNR) does not recommend swimming in the Chattahoochee River, as evidenced by the absence of swimming as a beneficial use for the river within the boundaries of the installation; however, recreation, including dermal contact, is a beneficial use within Lake W.F. George (GADNR EPD 2010). The portion of Lake W.F. George with a beneficial use of recreation is more than 16 miles downstream from the installation. Given the long distance from the installation (exceeding 15 miles), this receptor scenario is not evaluated further.

  Five ponds are listed by the Fort Moore Directorate of Family and Morale, Welfare, and Recreation, on its webpage, as on-installation recreational fishing areas. Russ Pond, Victory Pond, Twilight Pond, Weems Pond, and Kings Pond are located completely within the

installation and provide opportunities for fishing and subsequent ingestion of fish. The Kings Pond Recreation Area is completely surrounded by operational range area but is not included in the operational range footprint. Kings Pond is one of the most popular recreational use areas on the installation. Fishing is likely to occur along the Chattahoochee River within and immediately downstream from the installation and at Kings Pond.

The Operational Range Assessment Program (ORAP) Phase II Quantitative Assessment Report concluded that surface water detections within the preferential surface water and sediment sample location did not exceed the project action levels (PALs) and the data were indistinguishable from reference conditions (Arcadis 2012).

- ***Ecological Receptors***—Ecological receptors include sensitive environments (e.g., wetlands) and threatened and endangered species with habitat and/or foraging areas near the Chattahoochee River within 15 miles downstream. The bald eagle (*Haliaeetus leucocephalus*), American alligator (*Alligator mississippiensis*), and wood stork (*Mycteria americana*) are all known to exist within the Chattahoochee River directly south of Fort Moore. Ecological receptors (the Indiana bat [*Myotis sodalis*] and American bald eagle) may contact surface water and/or sediment via both dermal contact and ingestion. The American bald eagle was federally de-listed but is still protected under the Bald and Golden Eagle Protection Act. The American bald eagle can obtain fish from rivers, thus potentially being exposed via direct contact with surface water and indirect contact through ingestion of prey.

  Wetlands, which are considered sensitive environments, are considered potential ecological receptors. Wetlands exist throughout Fort Moore and within the 15-mile downstream area of Fort Moore. The wetland areas total approximately 1,235 acres, including the Chattahoochee River, within the installation boundary.

  Groundwater Use—The groundwater pathway is a potential concern for the downgradient domestic water supply wells east and south of Fort Moore. Water from these wells is used for drinking (ingestion), and activities leading to dermal contact, such as bathing (Arcadis 2011). However, the ORAP Phase II Quantitative Assessment Report concluded that groundwater that may be impacted by operational range activities does not leave the installation but discharges locally into adjacent surface water bodies (Arcadis 2012).

Potential human receptors include those outside of the installation boundaries that can interact via ingestion (incidental during recreational use and through surface water intakes for drinking), dermal contact, and/or ingestion of fish. Ecological receptors include sensitive environments (e.g., wetlands) and threatened and endangered species with habitat and/or foraging areas near the Chattahoochee River within 15 miles downstream.

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCAs at Fort Moore are listed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of samples from locations downstream from the RCAs at Fort Moore (Figures 1-2 and 1-3) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling locations at Fort Moore were selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***OC2***—The selected sampling point is located in the Oswichwee Creek downstream from the RCAs located in the southern portion of the installation (i.e., Hook Range, Patton Range, Burma Hill Range [Demo Area], Buchanon Range, Coolidge Range, and Brann Range) and in the Oswichwee Creek watershed.
- ***UC2***—The selected sampling point is in the Upatoi Creek downstream from the RCAs located in the northern portion of the installation (i.e., K-18 Range [Cactus OP] and K-15 Range [Concord OP/DUD Area]) and in the Upatoi Creek watershed.

The Phase II ORAP sample locations (i.e., RM1, KP1, and OH2) were not recommended for the environmental radiation monitoring (ERM) because of lack of hydrologic connection with the RCAs (Figures 1-2 and 1-3). In addition, the upstream reference locations sampled during the ORAP Phase II assessment (OC1, UC1, RC1, PC1, and OH1) will not be sampled during the ERM. Sampling will be conducted on the PAERMP's specified semiannual interval as the sampling locations are within perennial and free flowing areas.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCAs indicate that the uranium-238/uranium-234 (U-238/U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The selected downstream sampling locations, UC2 and OC2, for the ERM and the other ORAP Phase II assessment sample locations were sampled in 2011 and 2012. Surface water and sediment samples were analyzed for uranium (Arcadis 2012). The range of uranium concentrations that resulted from the sampling events in September/October, November, February, and March is presented in Tables 2-1 and 2-2.

Table 2-1. Uranium Surface Water Analytical Results From the 2011 and 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	Range of Concentrations (µg/L)
KP-1 (King's Pond)	4	0.003-0.005
OC-1 (Oswichee Creek)	2	0.070-0.135
OC-2 (Oswichee Creek)	5	0.008-0.026
OH-1 (Ochillee Creek)	4	0.008-0.043
OH-2 (Ochillee Creek)	5	0.009-0.192
PC-1 (Pine Knot Creek)	4	0.009-0.022
RC-1 (Randall Creek)	4	0.005-0.024
RM-1 (Red Mill Creek)	4	0.016-0.059
UC-1 (Upatoi Creek)	4	0.017-0.053
UC-2 (Upatoi Creek)	4	0.007-0.060

Table 2-2. Uranium Sediment Analytical Results From the 2011 and 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	Range of Concentrations (µg/L)
KP-1 (King's Pond)	3	0.460-0.590
OC-1 (Oswichee Creek)	3	1.100-2.000
OC-2 (Oswichee Creek)	6	0.130-0.230
OH-1 (Ochillee Creek)	3	0.190-0.240
OH-2 (Ochillee Creek)	2	0.190-0.230
PC-1 (Pine Knot Creek)	~	0.170-0.290
RC-1 (Randall Creek)	3	0.180-3.300
RM-1 (Red Mill Creek)	3	0.250-0.290
UC-1 (Upatoi Creek)	3	0.280-0.290
UC-2 (Upatoi Creek)	3	0.260-0.460

In accordance with the Site-Specific ERMP for Fort Benning, Georgia, Annex 2 (ML16265A235) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, UC2 and OC2, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6, in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a). The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Moore are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b);

Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (ML19115A040) (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
OC2	5/25/2017	ND
UC2	5/25/2017	ND
OC2	8/29/2017	ND
UC2	8/29/2017	ND
OC2	12/6/2017	ND
UC2	12/6/2017	ND
OC2	3/6/2018	ND
UC2	3/6/2018	ND
OC2	6/13/2018	ND
UC2	6/13/2018	ND
OC2	9/4/2018	ND
UC2	9/4/2018	ND
OC2	12/5/2018	ND
UC2	12/5/2018	ND
OC2	3/12/2019	0.93 ± 1.04
UC2	3/12/2019	0.35 ± 0.43
OC2	6/19/2019	ND
UC2	6/19/2019	0.56 ± 0.55
OC2	9/24/2019	ND
UC2	9/24/2019	ND
OC2	11/6/2019	ND
UC2	11/6/2019	ND
OC2	3/11/2020	ND
UC2	3/11/2020	ND
OC2	6/19/2020	ND
UC2	6/19/2020	ND
OC2	9/16/2020	ND
UC2	9/16/2020	ND
OC2	12/10/2020	ND
UC2	12/10/2020	ND
OC2	3/19/2021	NC
UC2	3/19/2021	NC
OC2	12/2/2021	NC
UC2	12/2/2021	NC
OC2	3/03/2022	0.86 ± 0.31
UC2	3/03/2022	NC
OC2	12/15/2022	NC
UC2	12/15/2022	0.85 ± 0.71

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
OC2	5/25/2017	1.0 ± 0.4
UC2	5/25/2017	1.1 ± 0.3
OC2	8/29/2017	1.1 ± 0.4
UC2	8/29/2017	1.15 ± 0.5
OC2	12/6/2017	0.88 ± 0.34
UC2	12/6/2017	ND
OC2	3/6/2018	1.2 ± 0.7
UC2	3/6/2018	0.77 ± 0.37
OC2	6/13/2018	1.1 ± 0.4
UC2	6/13/2018	0.81 ± 0.24
OC2	9/4/2018	0.81 ± 0.41
UC2	9/4/2018	1.0 ± 0.3
OC2	12/5/2018	0.92 ± 0.53
UC2	12/5/2018	1.0 ± 0.3
OC2	3/12/2019	1.0 ± 0.2
UC2	3/12/2019	1.0 ± 0.3
OC2	6/19/2019	0.78 ± 0.28
UC2	6/19/2019	0.97 ± 0.57
OC2	9/24/2019	0.88 ± 0.34
UC2	9/24/2019	0.79 ± 0.4
OC2	11/6/2019	1.0 ± 0.71
UC2	11/6/2019	0.79 ± 0.4
OC2	3/11/2020	1.1 ± 0.4
UC2	3/11/2020	0.90 ± 0.35
OC2	6/19/2020	1.3 ± 0.6
UC2	6/19/2020	ND
OC2	9/16/2020	0.66 ± 0.28
UC2	9/16/2020	0.79 ± 0.21
OC2	12/10/2020	1.1 ± 0.3
UC2	12/10/2020	0.80 ± 0.24
OC2	3/19/2021	0.86 ± 0.2
UC2	3/19/2021	0.89 ± 0.5
OC2	12/2/2021	1.1 ± 0.3
UC2	12/2/2021	1.1 ± 0.3
OC2	3/03/2022	0.93 ± 0.22
UC2	3/03/2022	0.99 ± 0.22
OC2	12/15/2022	1.1 ± 0.40
UC2	12/15/2022	0.92 ± 0.21

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Moore.

2.2 GROUNDWATER

Uranium was included as an analyte during the ORAP Phase II assessment groundwater sampling in June 2012 (U.S. Army 2014). The uranium concentrations resulting from the October/November/ December 2011 sampling event are presented in Table 2-5. The existing groundwater monitoring wells are shown in Figures 1-2 and 1-3.

Table 2-5. Uranium Groundwater Analytical Results

Sample Location	Number of Samples	Detected Concentration (µg/L)
SB1 (36-41 ft bgs)	1	0.008
SB1 (64-69 ft bgs)	1	0.071
SB4 (84-89 ft bgs)	1	0.004
SB4 (100-105 ft bgs)	1	0.007
SB4 (122-127 ft bgs)	1	0.05

Presently, no groundwater monitoring wells are located at or near the RCAs. In addition, groundwater in the shallowest aquifer discharges to the adjacent surface water bodies for the majority of the installation. Since shallow groundwater is known to discharge to surface water, any DU potentially present in groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020a), groundwater sampling is not planned for Fort Moore.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Moore does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020a).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within each of the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Moore will be coordinated with the Fort Moore Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (1,850 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Moore RCAs

Parameter		Default Value	LAE Field Z-4, Brann, Hook, Coolidge, Patton, Buchanon, K-15, and K-18 Ranges	Burma Hill Range	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone					
Soil concentrations (pCi/g)	U-234	N/A	0.182	2.34×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC Materials License. = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density) NOTE: 9 DU rounds (~ 2 kg) were associated with the Burma Hill Range Demo Area
	U-235	N/A	1.67×10^{-2}	2.14×10^{-4}	
	U-238	N/A	2.76	0.04	
Area of contaminated zone (m^2)		10,000	1,000,000	84,000	
Depth of contaminated zone (m)		2	0.15	0.15	NRC Radioactive Materials License SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	Depth to groundwater is generally 30 to 75 ft bgs
Length parallel to aquifer flow (m)		100	1,000	330	Length of RCA is approximately 1,000 m; Burma Hill diameter is 330 m
Contaminated zone total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand (Soil is sand with varying amounts of clay and silt)
Contaminated zone hydraulic conductivity (m/y)		10	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	7.4	7.4	www.usa.com for Fort Moore, GA
Precipitation rate (annual rainfall) (m/y)		1.0	1.1	1.1	www.usa.com for Fort Moore, GA
Saturated Zone					
Saturated zone total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone effective porosity		0.2	0.3	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone					
Unsaturated zone 1, thickness (m)		4.0	1.5	1.5	Depth to groundwater is generally 5 ft bgs
Unsaturated zone 1, total porosity		0.4	0.39	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.9	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	1,090	1,090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Moore RCAs

RCA Layout Parameter	Z-4 Range (LAE Field)				Brann Range				Hook Range			
Distance to nearest normally occupied area (m)	1,300				550				1,000			
Bearing of X axis (degrees)	135 (northeast)				90 (north)				45 (northwest)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	2,400	2,432	500	531.25	1,650	1,682	500	531.25	2,100	2,132
Leafy vegetables plot	500	531.25	2,434	2,466	500	531.25	1,684	1,716	500	531.25	2,134	2,166
Pasture, silage growing area	500	600	2,616	2,716	500	600	1,866	1,966	500	600	2,316	2,416
Grain fields	500	600	2,466	2,566	500	600	1,716	1,816	500	600	2,166	2,266
Dwelling site	500	531.25	2,300	2,332	500	531.25	1,550	1,582	500	531.25	2,000	2,032
Surface-water body	500	800	2,716	3,016	500	800	1,966	2,266	500	800	2,416	2,716
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	1,300				550				1,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1,716				966				1,416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				270				225			

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Moore RCAs (continued)

RCA Layout Parameter	Coolidge Range				Patton Range				Buchanon Range			
Distance to nearest normally occupied area (m)	450				800				950			
Bearing of X axis (degrees)	135 (northeast)				90 (north)				135 (northeast)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	1,550	1,582	500	531.25	1,900	1,932	500	531.25	2,050	2,082
Leafy vegetables plot	500	531.25	1,584	1,616	500	531.25	1,934	1,966	500	531.25	2,084	2,116
Pasture, silage growing area	500	600	1,766	1,866	500	600	2,116	2,216	500	600	2,266	2,366
Grain fields	500	600	1,616	1,716	500	600	1,966	2,066	500	600	2,116	2,216
Dwelling site	500	531.25	1,450	1,482	500	531.25	1,800	1,832	500	531.25	1,950	1,982
Surface-water body	500	800	1,866	2,166	500	800	2,216	2,516	500	800	2,366	2,666
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	450				800				950			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	866				1,216				1,366			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				270				315			

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Moore RCAs (continued)

RCA Layout Parameter	Burma Hill Range				K-15 Range				K-18 Range			
Distance to nearest normally occupied area (m)	400				400				650			
Bearing of X axis (degrees)	135 (northeast)				45 (northwest)				315 (southwest)			
X dimension of primary contamination (m)	290				1,000				1,000			
Y dimension of primary contamination (m)	290				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	790	822	500	531.25	1,500	1,532	500	531.25	1,750	1,782
Leafy vegetables plot	500	531.25	824	856	500	531.25	1,534	1,566	500	531.25	1,784	1,816
Pasture, silage growing area	500	600	1,006	1,106	500	600	1,716	1,816	500	600	1,966	2,066
Grain fields	500	600	856	956	500	600	1,566	1,666	500	600	1,816	1,916
Dwelling site	500	531.25	690	722	500	531.25	1,400	1,432	500	531.25	1,650	1,682
Surface-water body	500	800	1,106	1,406	500	800	1,816	2,116	500	800	2,066	2,366
Primary Contamination Parameter												
Length parallel to aquifer flow	290				1,000				1,000			
Atmospheric Transport Parameter												
Meteorological STAR file	GA_COLUMBUS.str				GA_COLUMBUS.str				GA_COLUMBUS.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	400				400				650			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	816				816				1,066			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				225				135			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Moore does not exceed 1.0×10^{-2} millisievert per year (mSv/y) (1.0millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Brann Range	0.32	0.33
Buchanon Range	0.32	0.31
Burma Hill Range	0.0045	0.0038
Coolidge Range	0.32	0.32
Hook Range	0.32	0.31
K-15 Range	0.32	0.35
K-18 Range	0.32	0.33
Patton Range	0.32	0.32
Z-4 Range	0.32	0.29

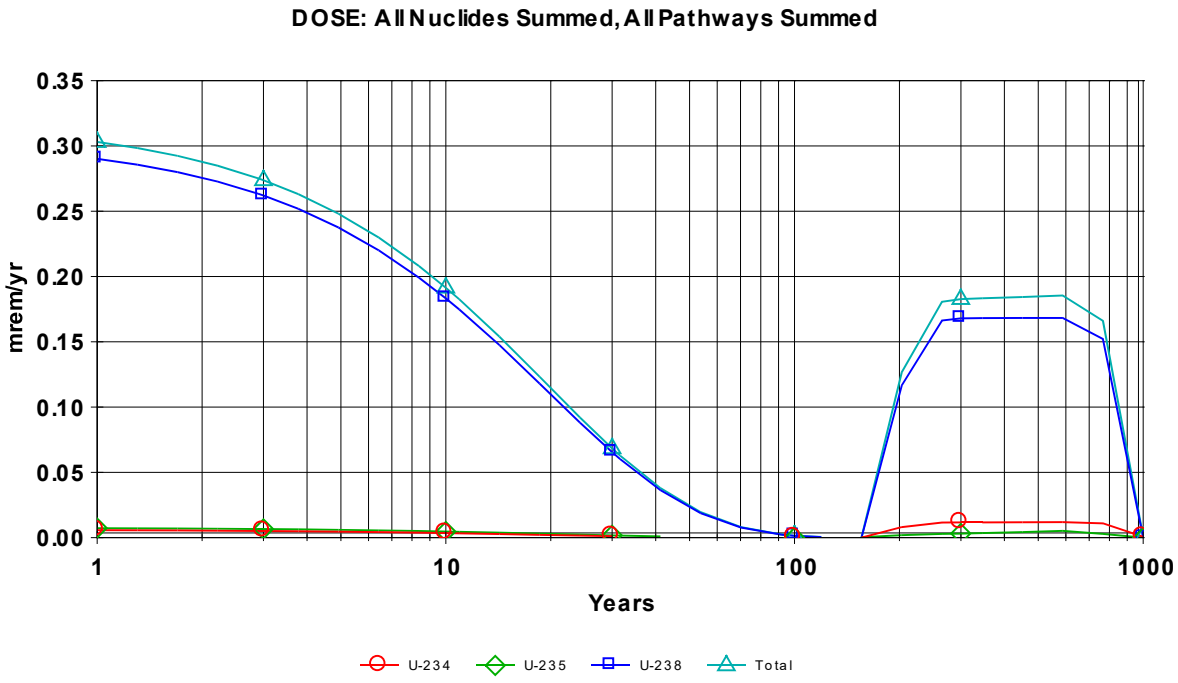
[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

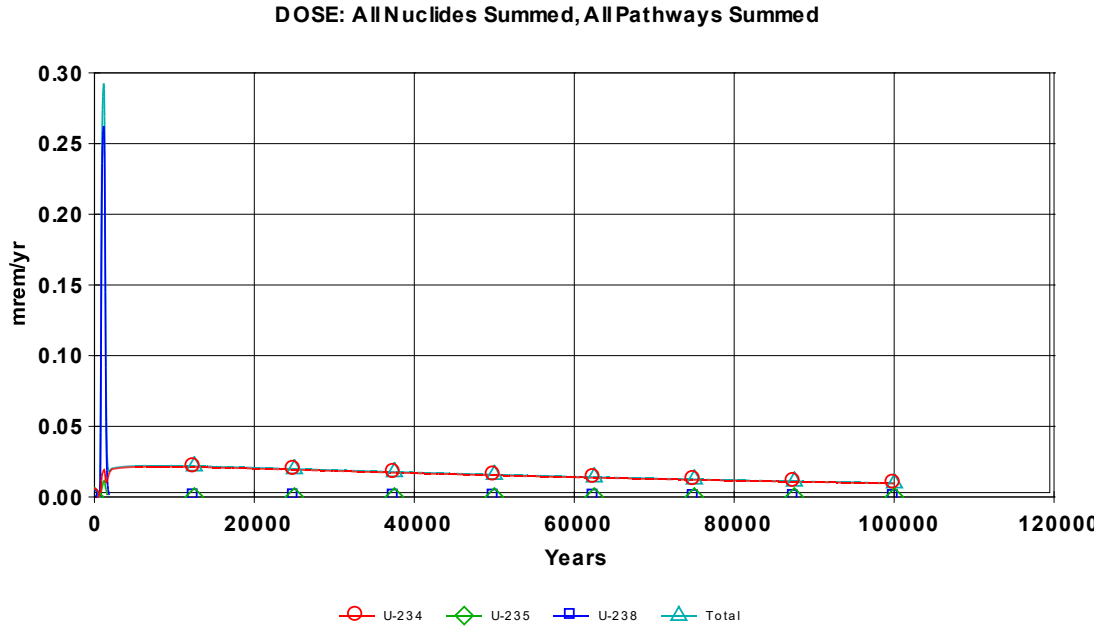
Figure 4-1. Residential Farmer Receptor Dose Graphs for Fort Moore RCAs

Z-4 Range

RCA Onsite (RESRAD)

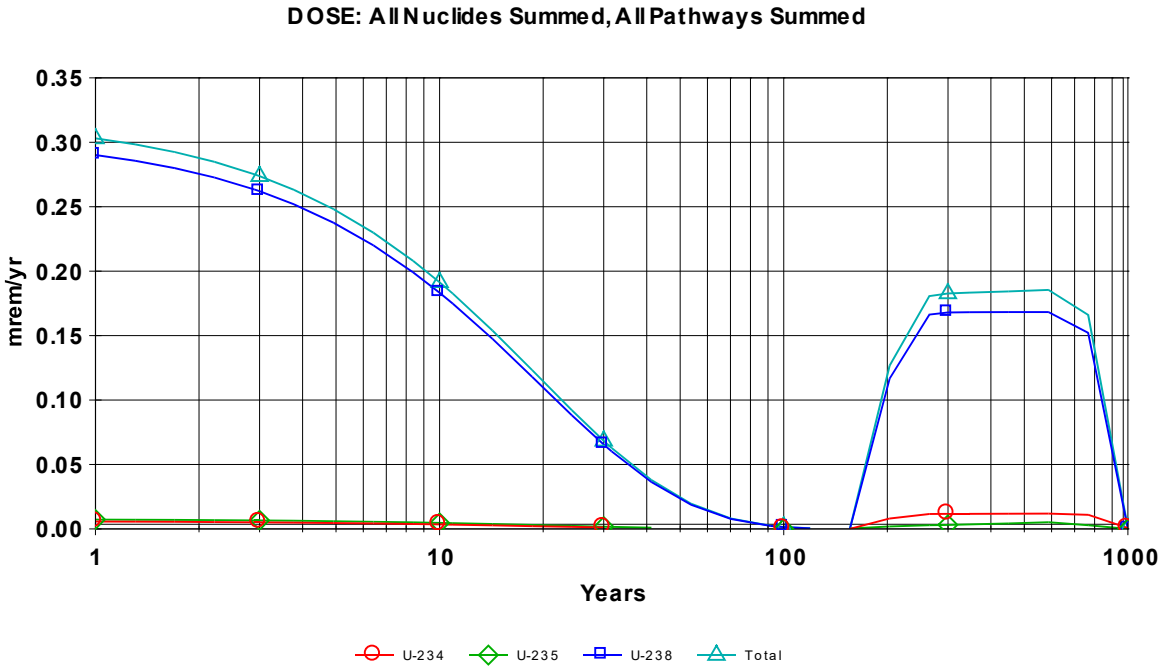


RCA Offsite (RESRAD-OFFSITE)



Brann Range

RCA Onsite (RESRAD)



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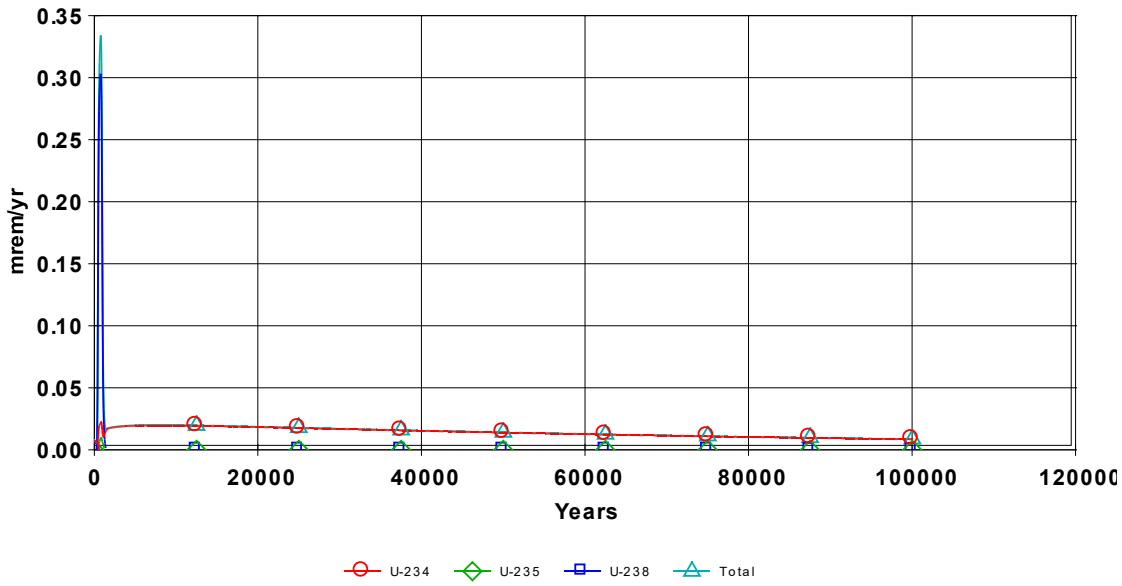
RCA Offsite (RESRAD-OFFSITE)



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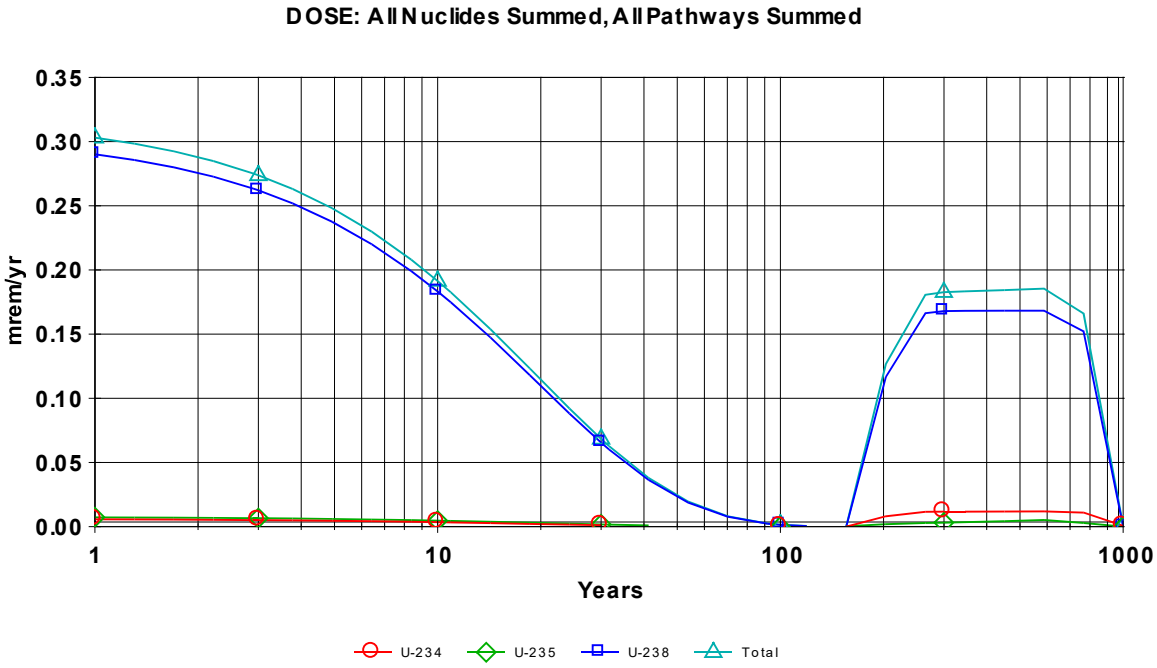
Hook Range

RCA Onsite (RESRAD)



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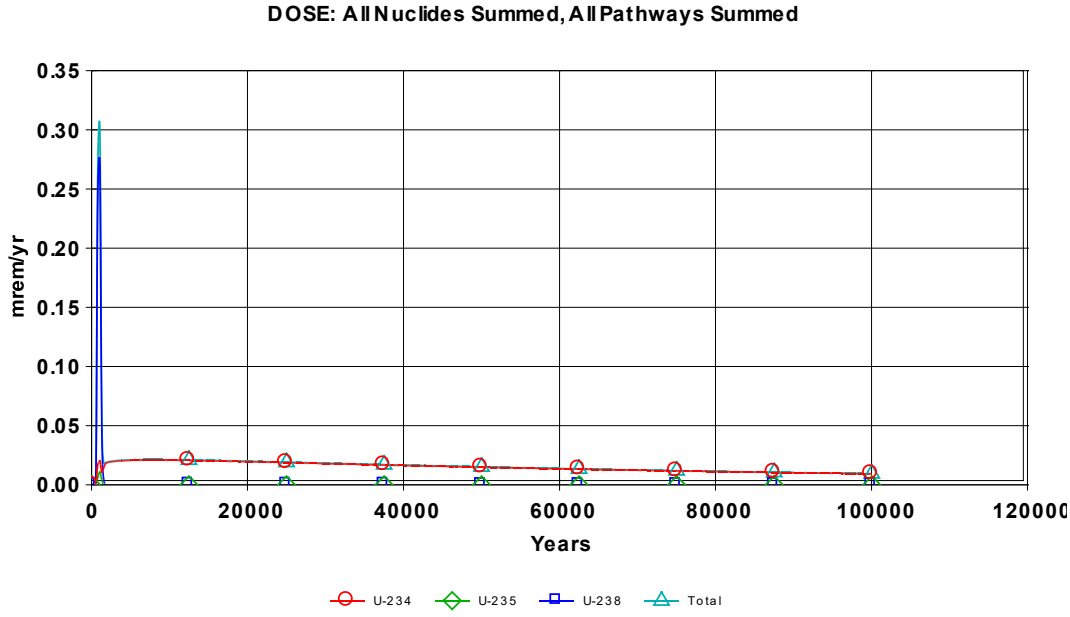
RCA Offsite (RESRAD-OFFSITE)



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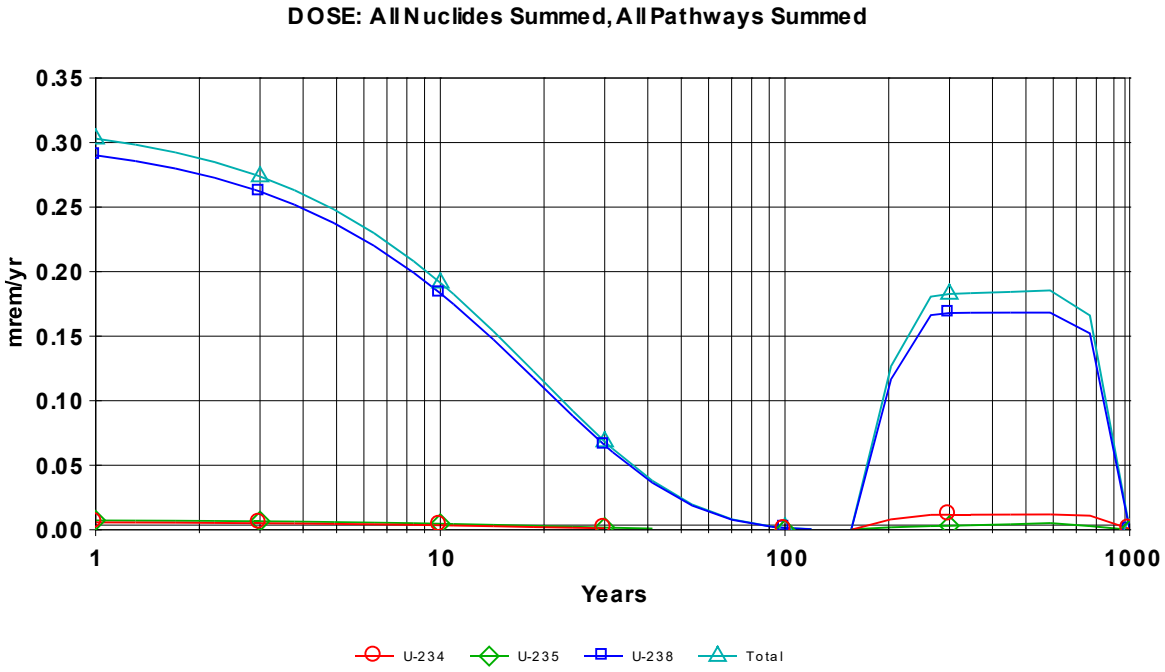
Coolidge Range

RCA Onsite (RESRAD)



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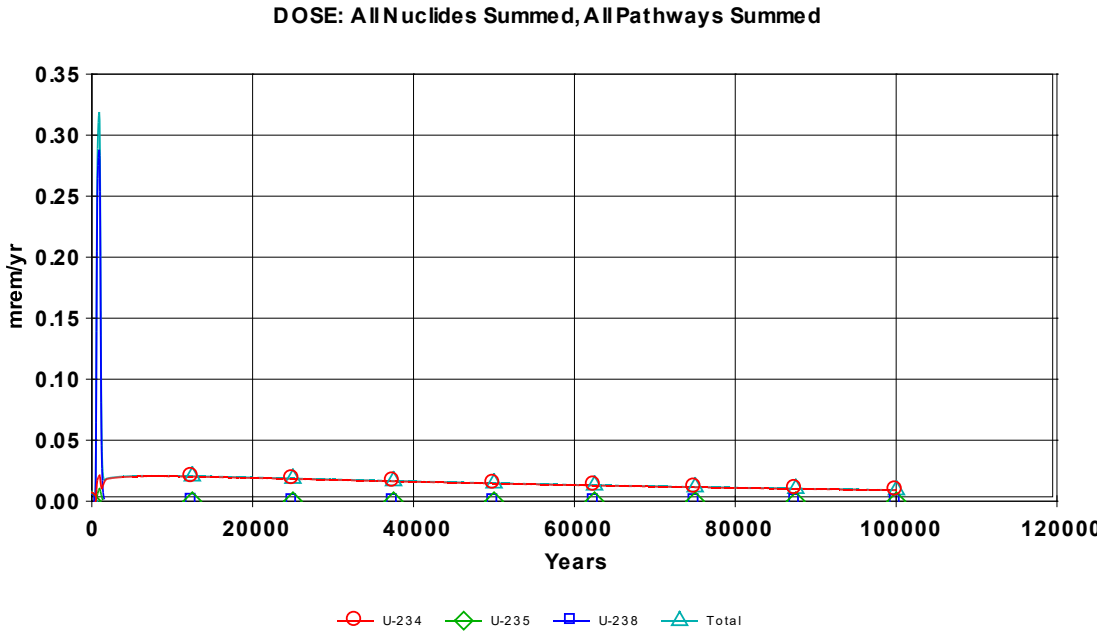
RCA Offsite (RESRAD-OFFSITE)



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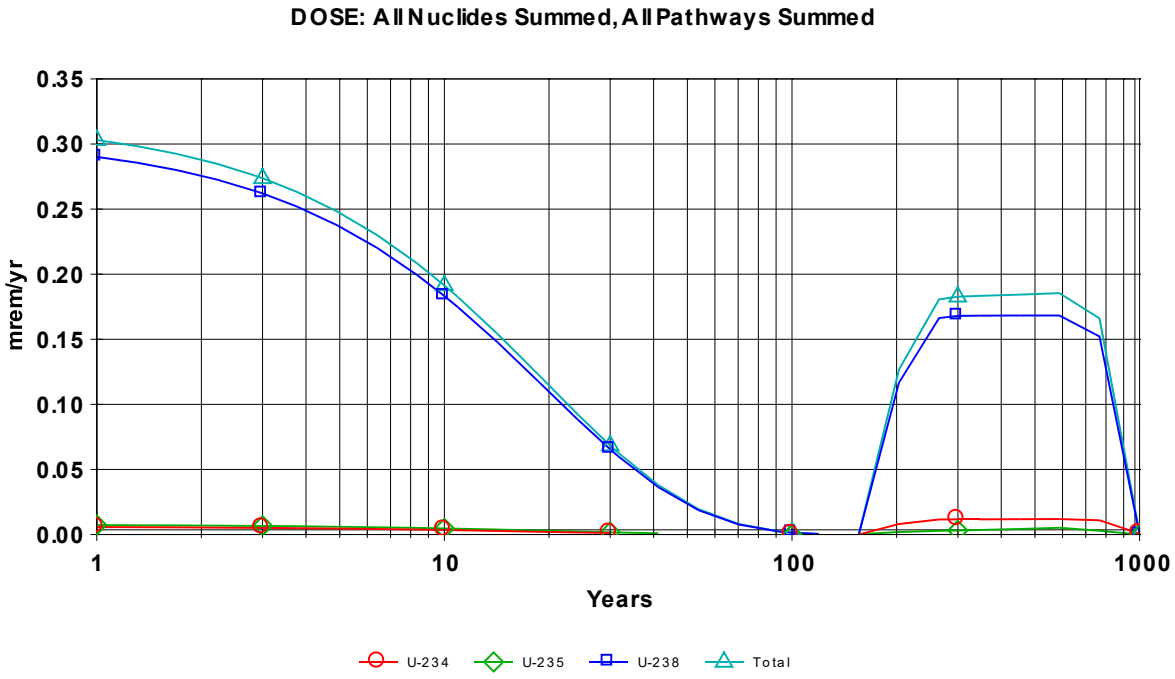
Patton Range

RCA Onsite (RESRAD)



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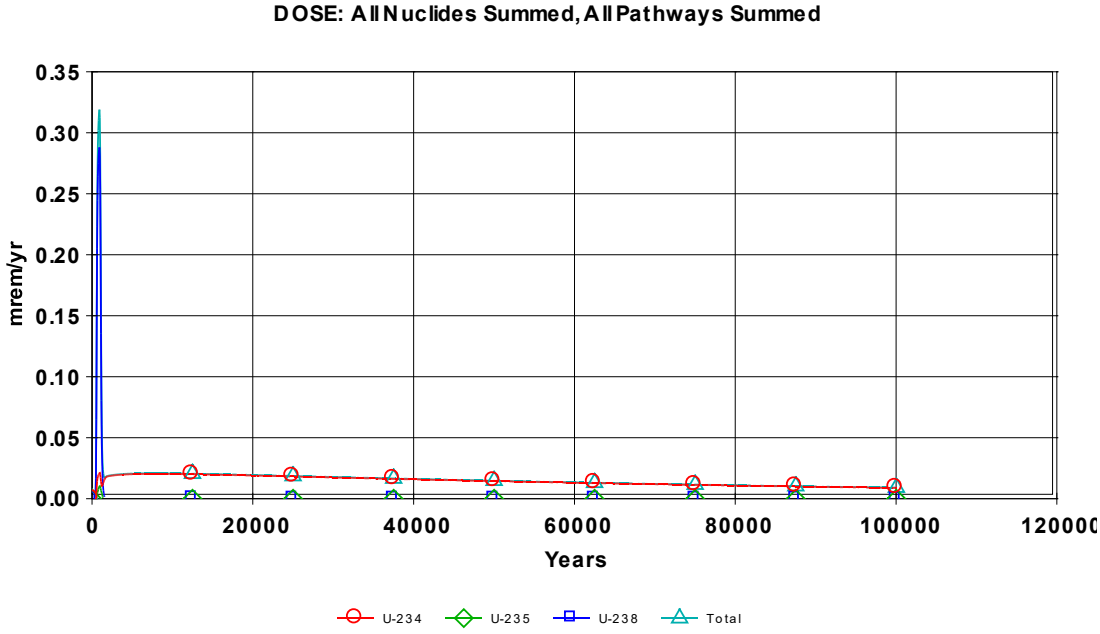
RCA Offsite (RESRAD-OFFSITE)



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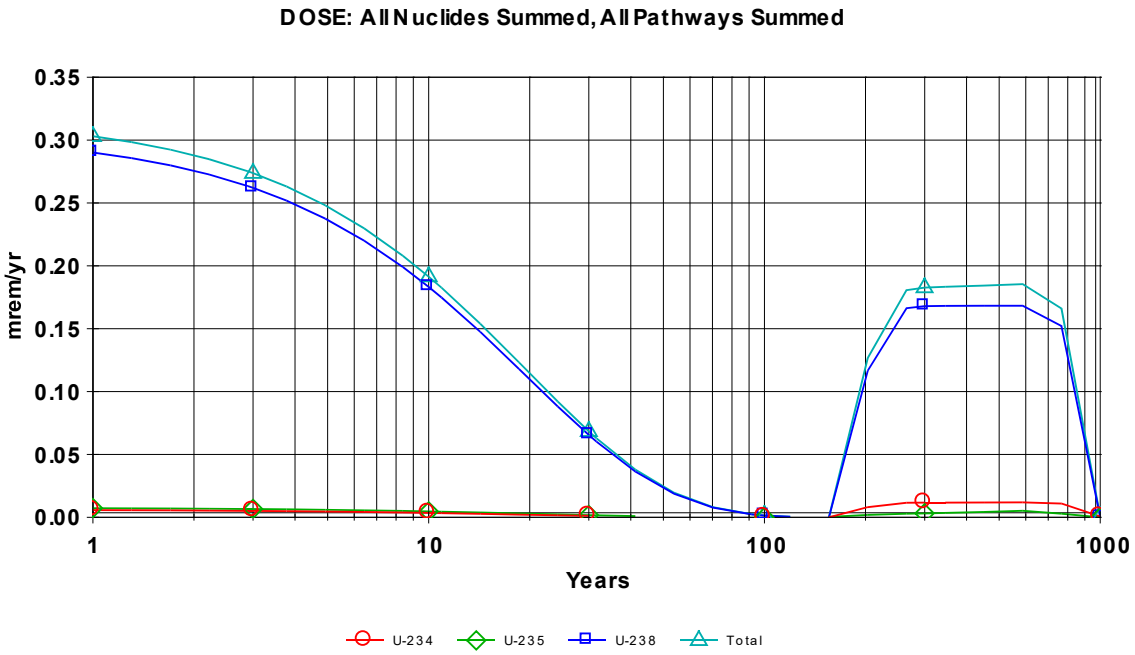
Buchanon Range

RCA Onsite (RESRAD)



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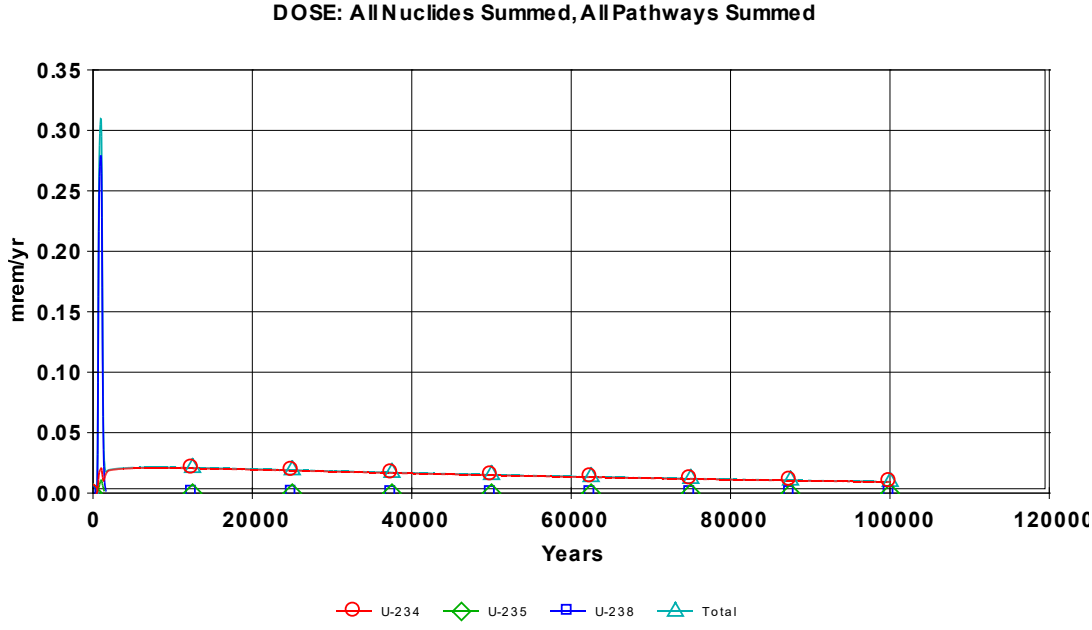
RCA Offsite (RESRAD-OFFSITE)



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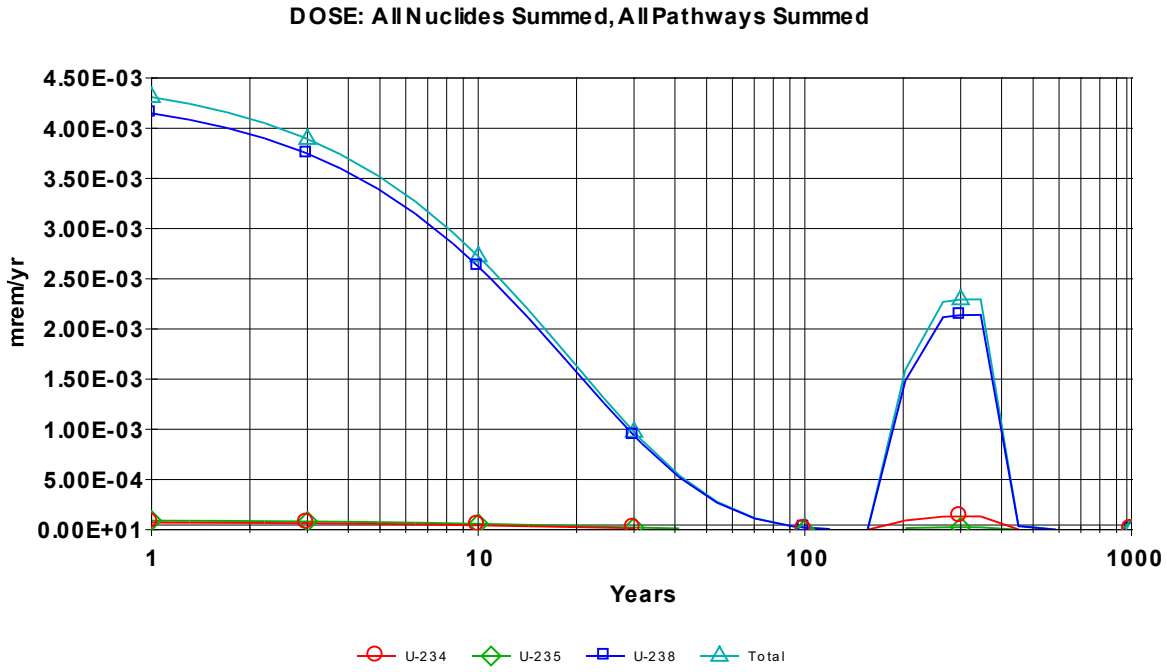
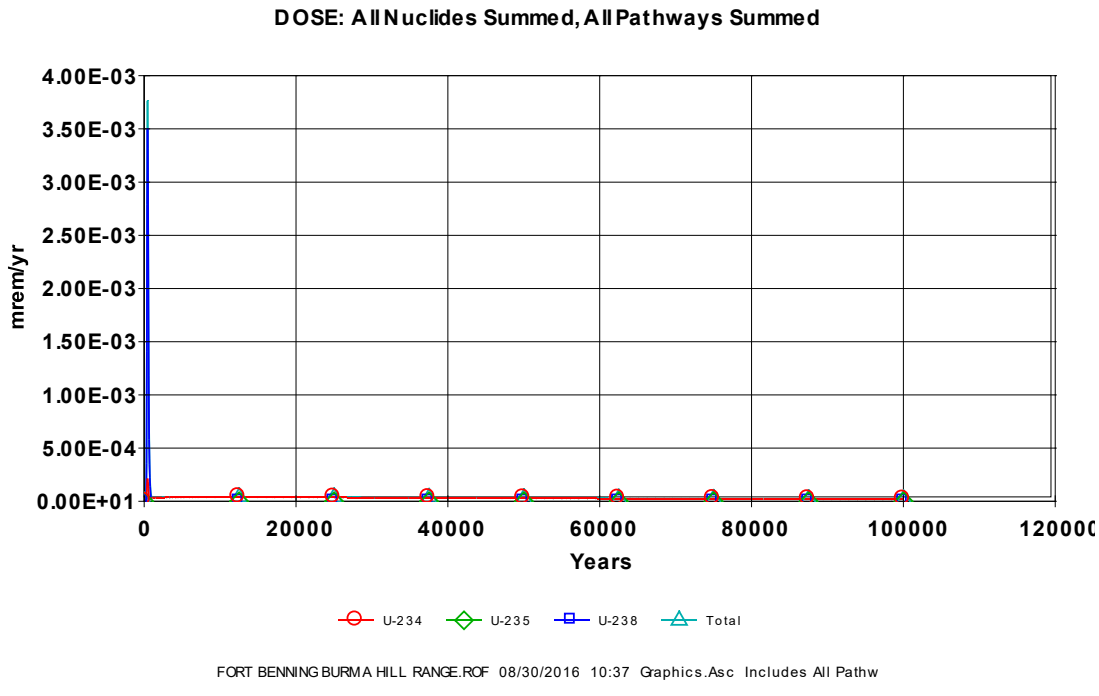
Burma Hill Range

RCA Onsite (RESRAD)

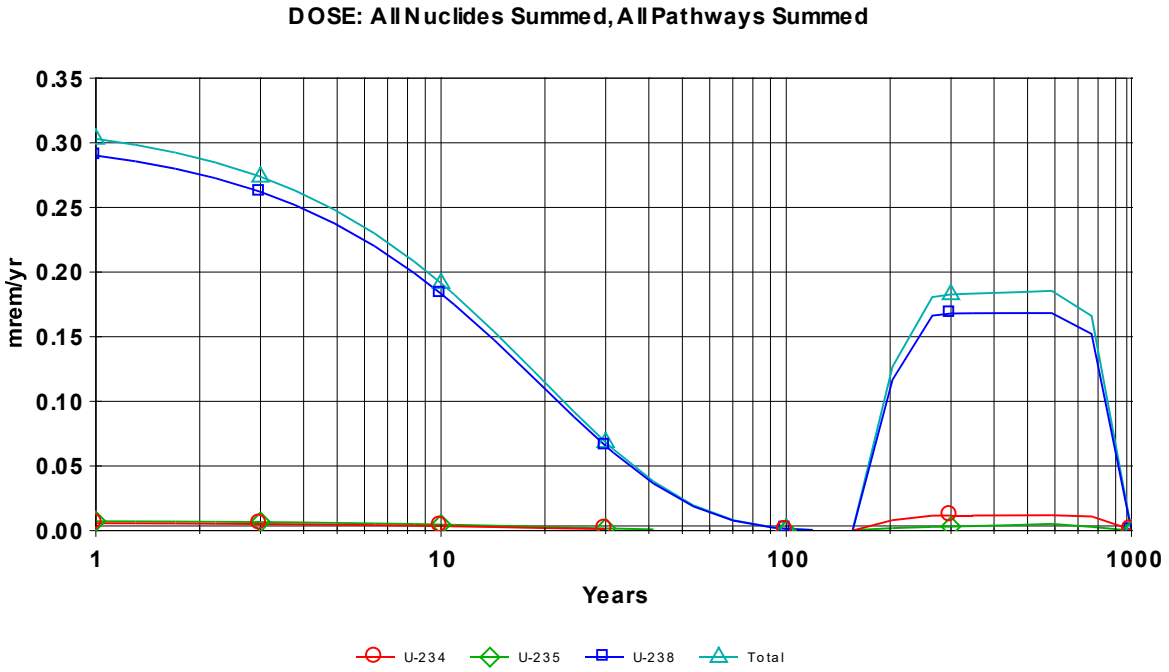


RCA Offsite (RESRAD-OFFSITE)

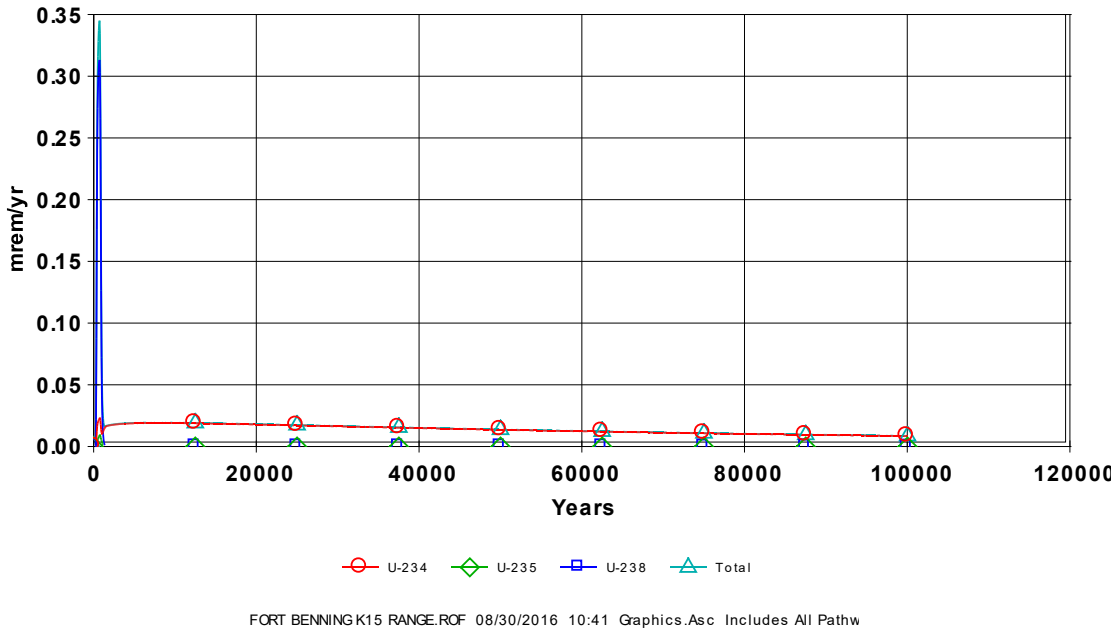


K-15 Range

RCA Onsite (RESRAD)

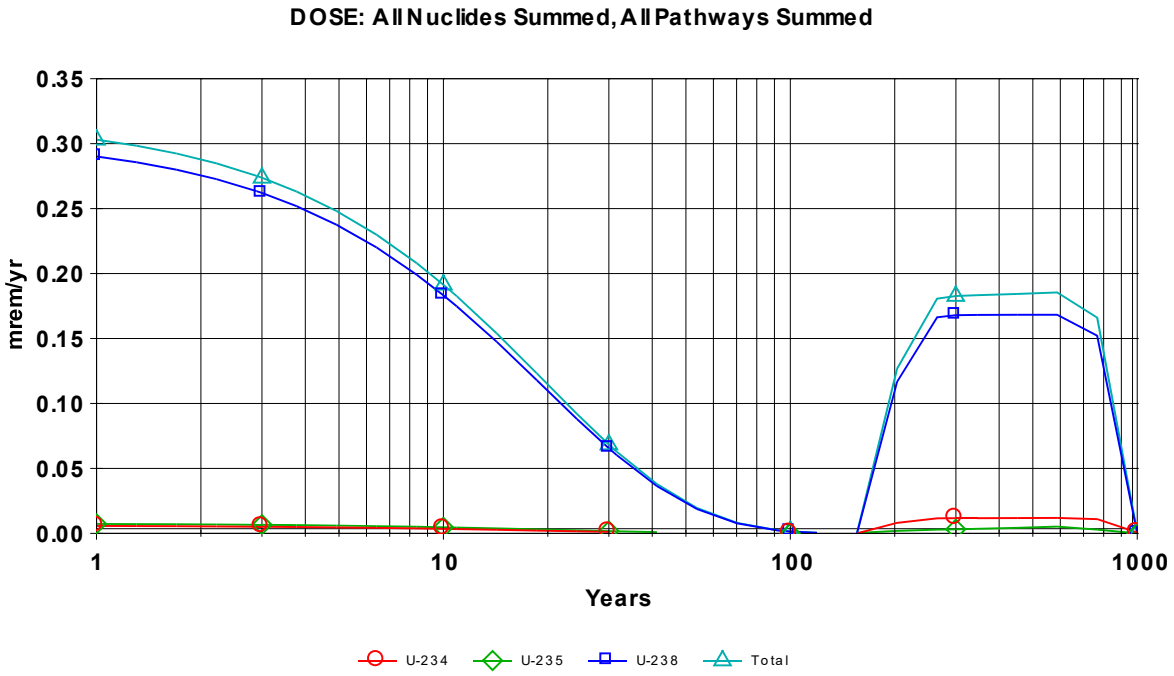


RCA Offsite (RESRAD-OFFSITE)

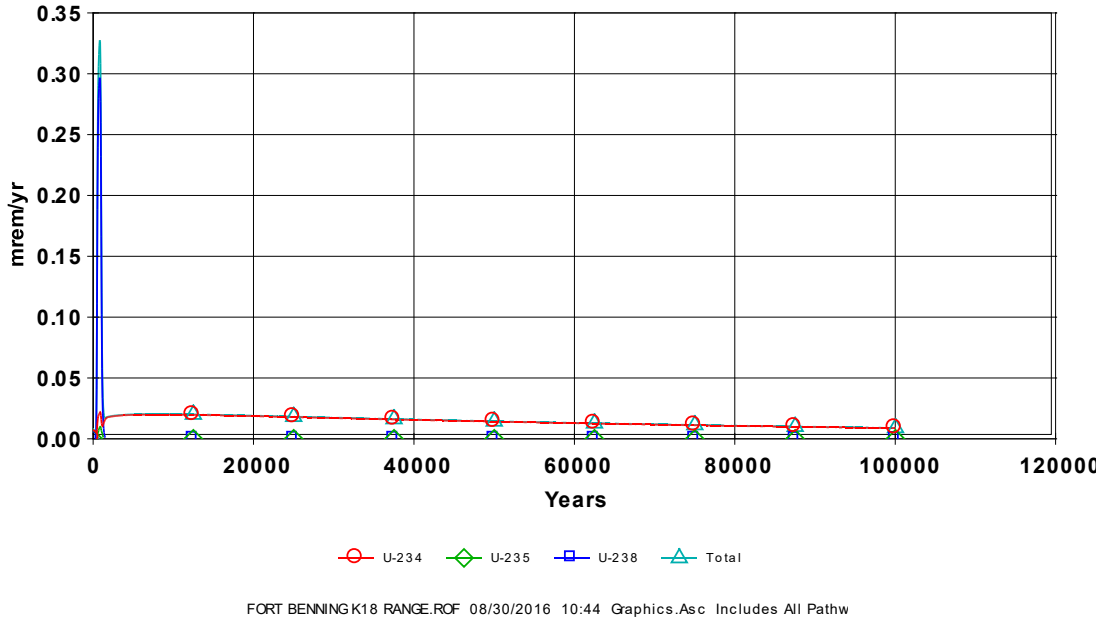


K-18 Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



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Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT LIBERTY, NORTH CAROLINA ANNEX 3

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RCW	Red-Cockaded Woodpecker
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
USGS	U.S. Geological Survey
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to Fort Liberty, North Carolina, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Bragg, North Carolina, Annex 3 (ML21165A013) (U.S. Army 2020a) and documents the Installation name change from Fort Bragg, North Carolina, to Fort Liberty, North Carolina, on June 2, 2023.

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Liberty. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
One co-located surface water and sediment sample downstream (**SWS-08**) from the OP-5 Range RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., lack of surface water from drought)

1.2 INSTALLATION BACKGROUND

Fort Liberty is an approximately 160,760-acre installation located in Cumberland, Harnett, Hoke, and Moore counties, just west of Interstate 95 adjacent to the cities of Fayetteville and Spring Lake, North Carolina (Figure 1-1).

In August 1918, the War Department issued orders establishing Camp Bragg as a Field Artillery Cantonment and, in 1919, initial construction was complete. In 1922, Camp Bragg was established as a permanent U.S. Army post and was renamed Fort Bragg. Once established as a permanent post, the installation's infrastructure was developed, and land acquisitions were made to accommodate a transition as a long-range artillery training area (TA). In the 1940s, the U.S. Army created the Airborne Command at Fort Bragg, and a number of airborne units were transferred to the installation for training. By the mid-1940s, Fort Bragg's soldier population had reached 100,000, including artillerymen, infantry divisions, and the 82nd Airborne. The soldier population and training role of Fort Bragg continued to grow and transition with advancements in military training and weapons throughout the installation's history. In 2023, Fort Bragg was renamed Fort Liberty.

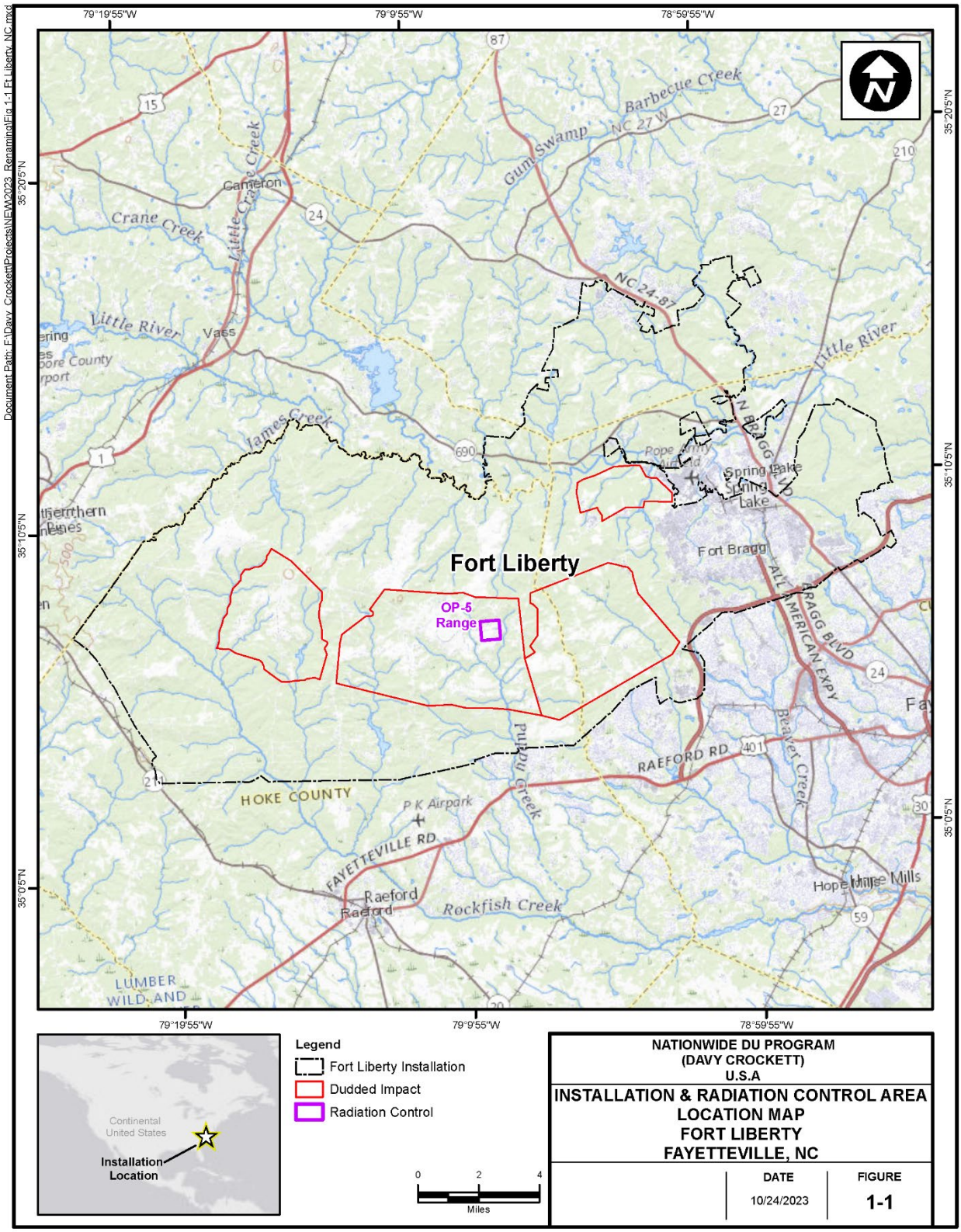

Figure 1-1. Installation and Radiation Control Area Location Map

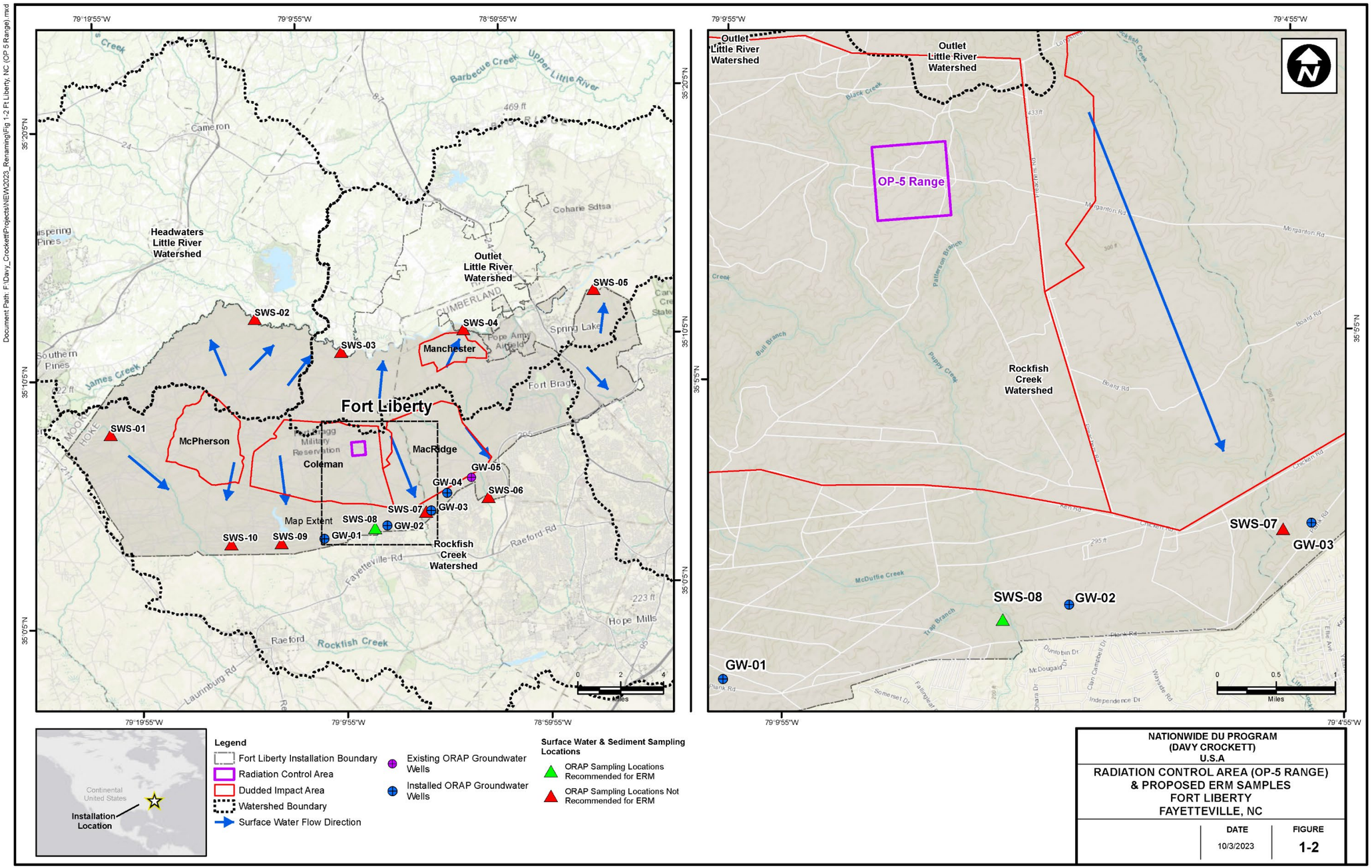

Figure 1-2. Radiation Control Area (OP-5 Range) and Selected ERM Samples

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As of today, Fort Liberty is the largest U.S. Army installation in the world (by population), providing a home to almost 10 percent of the U.S. Army's Active Component forces. The installation's current operational footprint includes 272 operational ranges and a 2,465-acre nonoperational cantonment area.

An Archives Search Report (ASR) (USACE 2008) confirmed the Davy Crockett weapon system was fielded and fired at Fort Liberty, North Carolina. Although remnants of the Davy Crockett weapon system were not found at Fort Liberty during the ASR inspection, the OP-5 Range was designated a radiation control area (RCA) and consists of approximately 248 acres, as shown in Figure 1-2. The nearest normally occupied areas to the OP-5 Range or RCA is located approximately 3.8 miles south of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained 6.7 ounces of DU and was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968.

These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly TA), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Fort Liberty; therefore, it is assumed that most, if not all, of the 810 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Liberty is located in the coastal plain physiographic unit characterized by mostly unconsolidated and partially consolidated sediments. Surface water drainage across Fort Liberty is divided into southern and northern portions by the Rockfish Creek and Little River watershed, respectively. Approximately 75 percent of Fort Liberty's range areas, including the OP-5 Range (Figure 1-2), lie within the Rockfish Creek watershed, while the remaining 25 percent are situated within the Little River watershed (EA 2014).

Rockfish Creek originates just west of the installation's boundary and serves as the primary drainage for the southern portion of Fort Liberty, including the OP-5 Range RCA. The creek flows southeast, before exiting Fort Liberty's southern boundary, then east before discharging into the Cape Fear River. Tributaries of Rockfish Creek (Juniper Creek, Nicholson Creek, Puppy Creek, Little Rockfish Creek, and Bones Creek) drain Fort Liberty's southern impact areas and discharge into the creek south of the installation boundary.

The Puppy Creek drainage system consists of its main channel as well as Rays Creek and McDuffie Creek, which feed it from the west. These streams bisect the OP-5 Range, directing flow to the south and southeast, before discharging into Rockfish Creek approximately 6.5 miles south of the range area boundary.

Surface soils within Fort Liberty's range areas, including the OP-5 Range, are composed of sands and loamy sands. Based on the rapid permeability rates of these sands, munitions constituents deposited on surface soils have the potential to mobilize into the shallow groundwater via vertical infiltration. The groundwater beneath Fort Liberty, which is generally encountered at 5 to 20 feet below ground surface (bgs), is contained within three primary aquifers (geologic formations): Middendorf, Cape Fear, and Saprolite-Basement.

The Middendorf aquifer is approximately 150 to 200 feet thick and consists of fluvial deposits resulting from meandering streams and rivers, which flowed from the northwest (EA 2011). This unconfined to semi-confined aquifer receives recharge from the vertical infiltration of surface water and precipitation. The Middendorf aquifer outcrops at approximately 90 percent of Fort Liberty's range areas. Flow direction within this shallow aquifer varies depending on location in relation to an east-west trending groundwater divide, but typically flows north-northeast or south-southeast from the divide. Shallow groundwater within close proximity of surface water flows toward and eventually discharges into on-range surface water streams and tributaries, which laterally and vertically bisects much of Fort Liberty's range area. The Middendorf aquifer is classified as a water table aquifer and serves as the primary supply of potable water for residential and commercial/industrial communities located off the installation (EA 2014).

Potential munitions constituents deposited on the surface soils within the OP-5 Range may mobilize into Middendorf aquifer, which outcrops within the Puppy Creek subwatershed, via vertical infiltration. Once in the shallow groundwater, munitions constituents can be transferred to the south toward Puppy Creek. There are six community wells (screened within the Middendorf aquifer) within 4 miles and downgradient from the Puppy Creek subwatershed. These wells occur in two distinct clusters, which are located approximately 3 miles apart. The westernmost cluster consists of two wells, located approximately 3 miles south of the range area's southern boundary. The eastern cluster of wells consists of four wells, located approximately 1.5 miles south of the range area's southern boundary.

The deeper Cape Fear aquifer is composed of clay interbedded with silt and silty sand. This confined aquifer, which is overlain by a thick layer of clay (upper Cape Fear Confining Unit), has an average thickness of 100 to 150 feet and does not receive recharge from the overlying shallow aquifers or through vertical infiltration of precipitation on the installation.

The Saprolite-Basement aquifer consists of unfractured metamorphic and crystalline Cambrian and Precambrian basement rocks. Because this aquifer contains limited water, it is not used as a water source for wells in the region. This aquifer is not utilized as a primary water source and is hydraulically separate from the overlying aquifers.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the OP-5 Range RCA at Fort Liberty are as follows:

- ***Surface Water Use***—Surface water surrounding Fort Liberty, including the Little River, Rockfish Creek, and their tributaries, are utilized for recreational activities and contain sensitive environments, habitats, and ecological receptors. No known use of surface water exists for consumption of drinking water downstream from Fort Liberty.
- ***Recreational Use***—Recreational activities occurring within 15 miles and downgradient from Fort Liberty include boating, fishing, and swimming in the Little River, Rockfish Creek, and their tributaries.

- ***Sensitive Environments***—Sensitive environments at and around Fort Liberty include wetlands, wetland areas, and habitats used by federally protected species (e.g., American chaffseed [*Schwalbea Americana*], Michaux's sumac [*Rhus michauxii*], red-cockaded woodpecker [RCW] [*Picoides borealis*], rough-leaved loosestrife [*Lysimachia asperulifolia*], and Saint Francis' satyr [*Neonympha mitchellii francisci*]). The installation and surrounding area are home to the second largest endangered RCW population in the world. About 90,000 acres of longleaf pine are found at Fort Liberty and Camp Mackall, making it the largest federally owned longleaf pine forest in the country. The endangered Saint Francis' satyr is also found on Fort Liberty. Loss of the wetland habitat is a primary threat to the Saint Francis' satyr. It is also estimated that approximately 9,570 acres of wetlands are within Fort Liberty.
- ***Habitat***—There are numerous species that occur or may occur at Fort Liberty or in the surrounding community that have been designated a special status at the Federal and/or state level based on their risk of extirpation or decline. The RCW is unique among woodpeckers in that it excavates cavities, used for roosting and nesting, in old living pine trees. Bordering the cantonment area to the west and south is the crescent-shaped Greenbelt, a forested area that supplies habitat for the RCW. The Saint Francis' satyr is one of the rarest and least known American butterflies; its habitat consists primarily of open wet meadows, interspersed with woody stems and dominated by a high diversity of sedges and other wetland grasses. In the North Carolina sandhills, such meadows are often relicts of abandoned beaver impoundments. Other wetland habitat types may be suitable habitat. It appears beavers and frequent fires play an important role in habitat development. Larger pitcher plant bogs may be breeding sites based on numbers of butterflies observed, compared to smaller, linear shaped pocosins, which appear to be dispersal pathways.
- ***Ecological Receptors***—A total of 110 threatened and endangered nonvascular/vascular plants, including silvery sedge, twig rush, and Venus flytrap, were identified in Cumberland, Hoke, Hartnett, and Moore Counties in North Carolina. The Fort Liberty Endangered Species Branch manages five federally endangered species through the management of the longleaf pine/wiregrass ecosystem, which exists on and off-range. The eight threatened and endangered species found on and surrounding Fort Liberty are as follows: American chaffseed, Michaux's sumac, RCW, rough-leaved loosestrife, Saint Francis' satyr, American alligator, bald eagle, and the Cape Fear shiner. In addition, 179 sensitive species are located in the area surrounding Fort Liberty.
- ***Groundwater Use***—Groundwater is not currently used as a drinking water source for Fort Liberty's cantonment area. Groundwater wells within the cantonment area provide irrigation water for the Fort Liberty golf courses. In addition, a number of on-range supply wells provide non-potable water for isolated range areas. Groundwater from the Middendorf aquifer is utilized by a number of off-range/installation residential and commercial/industrial communities within 4 miles downgradient from current and historical source areas.

Potential human receptors include off-range/installation residential and commercial/industrial communities relying on potential public and private wells within 4 miles downgradient from Fort Liberty for potable water. In addition, the creeks flow directly into sensitive wetlands and may serve as habitat for several special status species that are considered ecological receptors.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the OP-5 Range at Fort Liberty are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the collection of one sample from SWS-08, a location downstream from the OP-5 Range RCA (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling location downstream from the OP-05 Range near the installation boundary was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-08***—The selected sampling point is located on Puppy Creek, downstream from the RCA, which is within the eastern two-thirds of the Coleman Impact Area. The Puppy Creek drainage system consists of a main channel as well as Rays Creek and McDuffie Creek, which feed it from the west. These streams dissect the Coleman Impact Area and the RCA, directing flow to the south and southeast adjacent to a number of live-fire ranges, before discharging into Rockfish Creek approximately 6.5 miles south of the range area boundary. SWS-08 was selected as a surface water exit point of Puppy Creek downstream from the eastern half of the Coleman Impact Area and the RCA and near the Fort Liberty boundary.

Historical surface water and sediment sample locations SWS-01 through SWS-07, SWS-09, and SWS-10 will not be sampled during the environmental radiation monitoring (ERM). The selected ERM sampling location is focused on Puppy Creek because the locations are downstream from the OP-5 Range RCA. SWS-01 and SWS-02 are upstream reference locations and SWS-03 (Mill Creek), SWS-04 (Cypress Creek), SWS-05 (Gibson Creek), SWS-06 (Bones Creek), SWS-07 (Little Rockfish Creek), SWS-09 (Nicholson Creek), and SWS-10 (Juniper Creek) are not downstream from the RCA.

The surface water and sediment sample will be analyzed for total/isotopic uranium using the U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to

determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

Sediment was sampled at the selected ERM downstream sampling location, SWS-08, during the Operational Range Assessment Program (ORAP) Phase II assessment in 2011 and 2013 and analyzed for uranium (EA 2014). The range of U-238/U-234 activity ratios from the May 2011, October 2011, and May 2013 sediment sampling events are presented in Table 2-1.

Table 2-1. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2011 and 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio* (unitless)
Downstream (Puppy Creek)	3	0.86-0.89
Reference (Jennie Creek)	3	0.48-1.27

* The U-238 to U-234 activity ratio and the weight percent U-235 mass ratio are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Fort Bragg, North Carolina, Annex 3 (ML16265A237) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, SWS-08, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6, in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a). The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Liberty are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b); Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (ML19115A040) (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-2 and 2-3.

Table 2-2. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-08	5/23/2017	ND
SWS-08	8/29/2017	ND
SWS-08	11/29/2017	ND
SWS-08	4/5/2018	ND
SWS-08	6/7/2018	ND
SWS-08	9/12/2018	ND
SWS-08	12/12/2018	ND
SWS-08	2/20/2019	ND
SWS-08	5/30/2019	0.29 ± 0.34
SWS-08	9/25/2019	ND
SWS-08	11/6/2019	ND
SWS-08	3/5/2020	ND
SWS-08	5/26/2020	ND

Table 2-2. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events (Continued)

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-08	9/22/2020	ND
SWS-08	11/3/2020	ND
SWS-08	3/2/2021	NC
SWS-08	9/8/2021	NC
SWS-08	3/22/2022	NC
SWS-08	7/19/2022	NC

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-3, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at Fort Liberty.

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-08	5/23/2017	1.2 ± 0.4
SWS-08	8/29/2017	0.85 ± 0.31
SWS-08	11/29/2017	1.2 ± 0.3
SWS-08	4/5/2018	0.77 ± 0.2
SWS-08	6/7/2018	0.87 ± 0.23
SWS-08	9/12/2018	0.70 ± 0.18
SWS-08	12/12/2018	0.92 ± 0.21
SWS-08	2/20/2019	0.95 ± 0.24
SWS-08	5/30/2019	0.94 ± 0.17
SWS-08	9/25/2019	0.91 ± 0.31
SWS-08	11/6/2019	0.90 ± 0.26
SWS-08	3/5/2020	0.98 ± 0.28
SWS-08	5/26/2020	0.79 ± 0.2
SWS-08	9/22/2020	1.0 ± 0.3
SWS-08	11/3/2020	0.86 ± 0.29
SWS-08	3/2/2021	1.1 ± 0.3
SWS-08	9/8/2021	0.85 ± 0.2
SWS-08	3/22/2022	0.94 ± 0.31
SWS-08	7/19/2022	1.2 ± 0.41

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

2.2 GROUNDWATER

One groundwater monitoring well located downgradient from the OP-5 Range RCA (GW-02) was sampled for uranium during the ORAP Phase II assessment. Groundwater samples collected from January 31 through March 1, 2012, were analyzed for uranium (EA 2014). The U-238/U-234 activity ratio

from the 2012 sampling event is presented in Table 2-4. The existing groundwater monitoring wells are shown in Figure 1-2.

Table 2-4. U-238/U-234 Activity Ratio for the Groundwater Sample

Sample Location	Number of Samples	U-238/U-234 Ratio* (unitless)
GW-01	1	0.75

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

Presently, no groundwater wells are located at or near the RCA. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For this reason and additional rationale included in the PAERMP (U.S. Army 2020a), groundwater sampling is not planned for Fort Liberty.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Liberty does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020a).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Liberty will be coordinated with the Fort Liberty Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this site-specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sample collection will start downstream and move upstream, and sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations

within the stream beds should be selected where the surface water flow is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located in the RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (810 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Liberty RCA

Parameter		Default Value	Fort Liberty OP-5 Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	7.97×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	7.29×10^{-3}	
	U-238	N/A	1.21	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 5 to 20 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Contaminated zone hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	0.5	State Climate Office of North Carolina
Precipitation rate (annual rainfall) (m/y)		1.0	1.2	State Climate Office of North Carolina
Saturated Zone				
Saturated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	1,090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Saturated zone b parameter		5.3	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, soil- specific b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Liberty RCA

RCA Layout Parameter	OP-5 Range			
Distance to nearest normally occupied area (m)	740			
Bearing of X axis (degrees)	292.5 (west-northwest)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	7100	7132
Leafy vegetables plot	500	531.25	7134	7166
Pasture, silage growing area	500	600	7316	7416
Grain fields	500	600	7166	7266
Dwelling site	500	531.25	7000	7032
Surface-water body	500	800	7416	7716
Atmospheric Transport Parameter				
Meteorological STAR file	NC_FAYETTEVILLE.str			
Length parallel to aquifer flow	1000			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	740			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1,156			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	112.5			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Liberty does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Liberty OP-5 Range	0.18	0.073

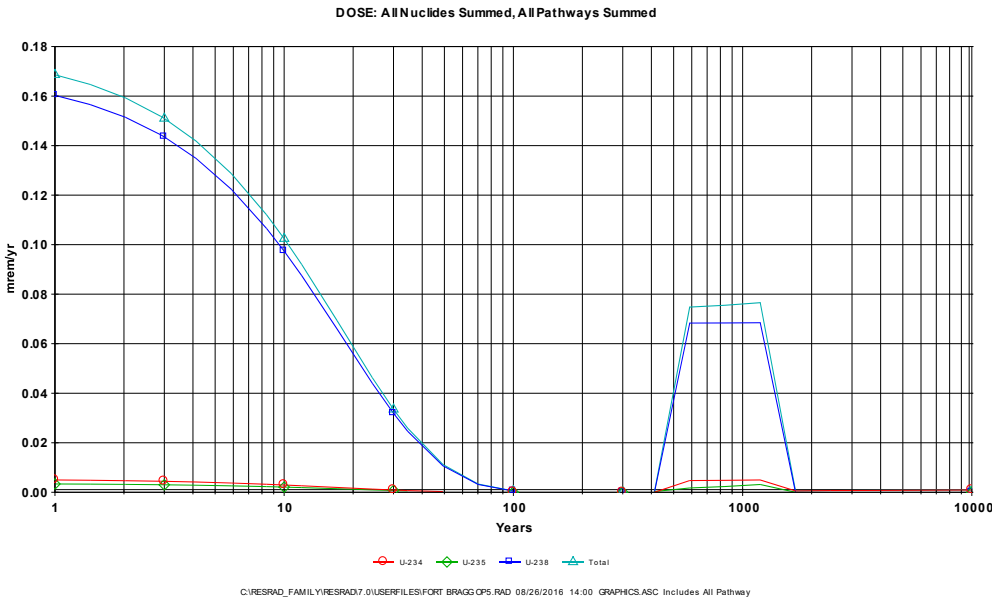
[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

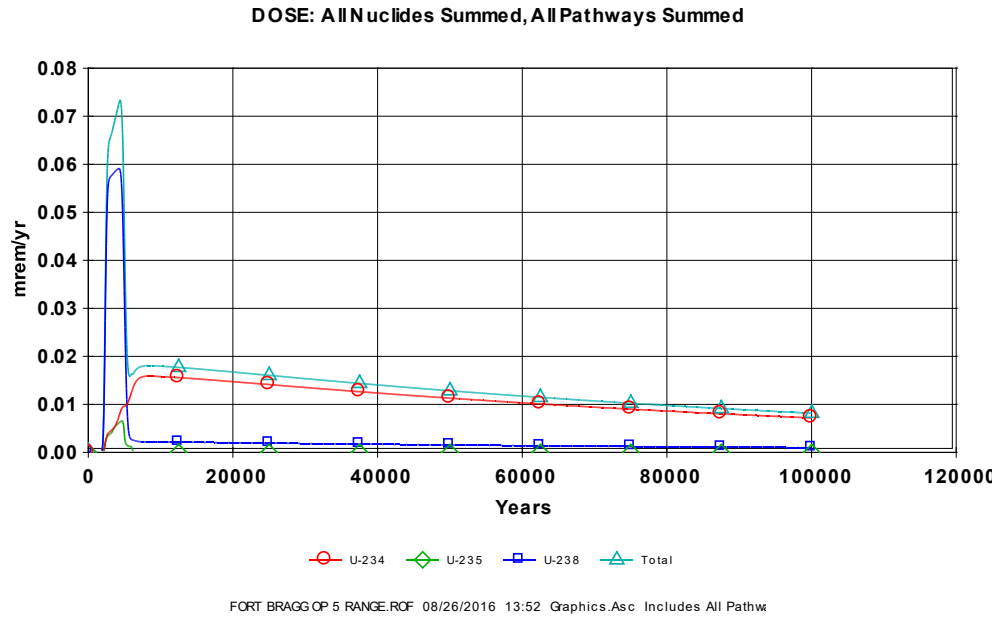
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Liberty OP-5 Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT CAMPBELL, KENTUCKY ANNEX 4

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CG	Commanding General
CFR	Code of Federal Regulations
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
Tot-U	Total Uranium
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance
WW II	World War II

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Campbell, Kentucky, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Campbell, Kentucky, Annex 4 (ML16265A238) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system on Fort Campbell. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream (**SWS-09**) from OP2/OP3 Range RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Campbell is in excess of 105,000 acres located in southwestern Kentucky and north-central Tennessee, approximately 50 miles northwest of Nashville, Tennessee (Figure 1-1). The installation is situated in portions of Christian and Trigg Counties in southwestern Kentucky and Stewart and Montgomery Counties in north-central Tennessee. A total of 95 operational ranges cover 91,118 acres; the Main Cantonment Area (administration, housing, storage, and maintenance) covers approximately 13,800 acres; and the remaining acreage is used for training purposes (EA 2014).

The installation was originally referred to as Camp Campbell and was officially commissioned in March 1942 as a major armor training and mobilization center for the World War II (WWII) effort. Camp Campbell was converted into an assembly and redevelopment center for troops returning from battle following WWII. In 1949, Camp Campbell began a transformation from an armored post to an airborne post. The 101st Airborne Division replaced the 11th Airborne Division in 1956 and, in 1959, the installation was transferred from the U.S. Air Force to the U.S. Army. Camp Campbell was designated as U.S. Army Garrison Fort Campbell on April 14, 1959 (EA 2014).

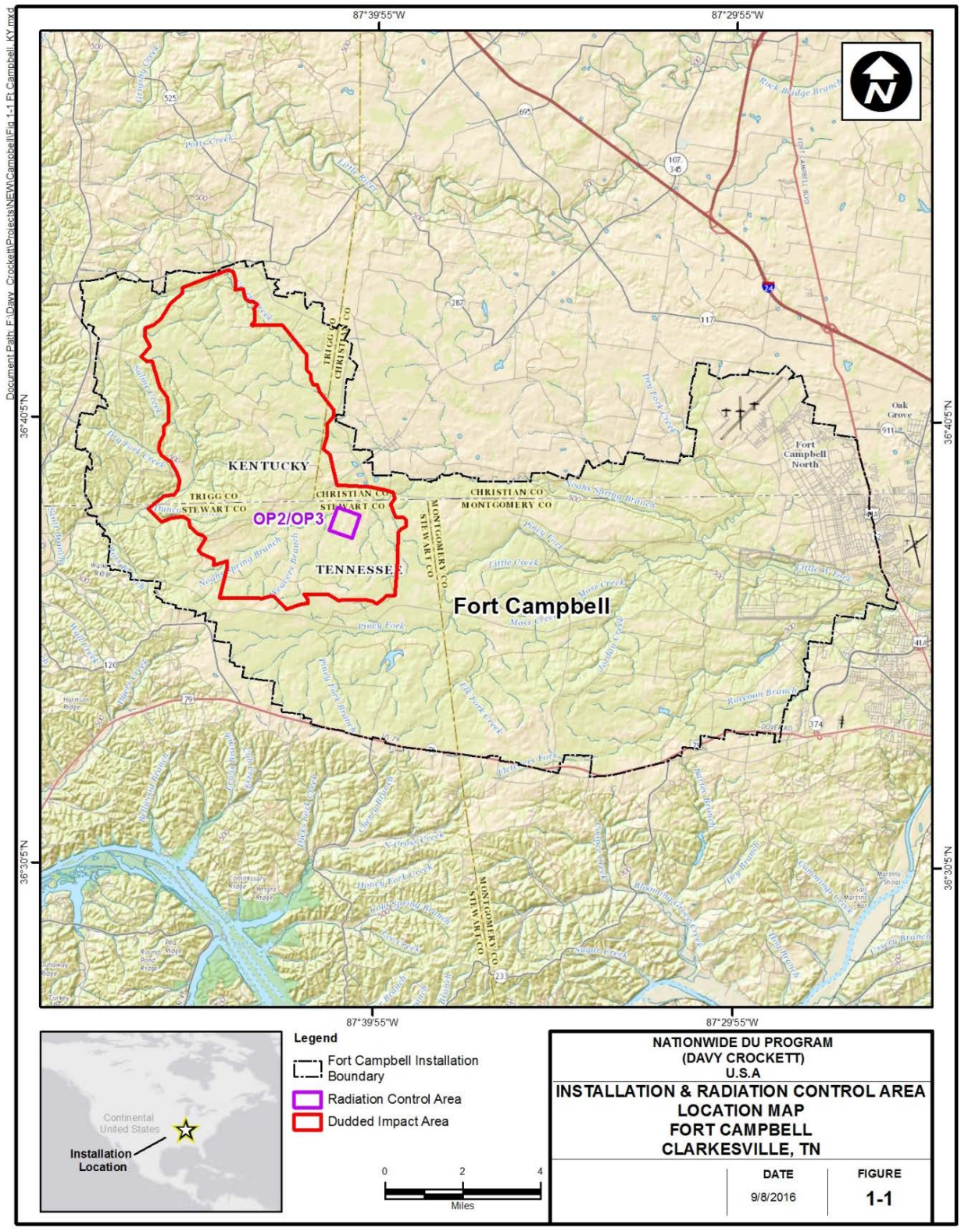

Figure 1-1. Installation and Radiation Control Area Location Map

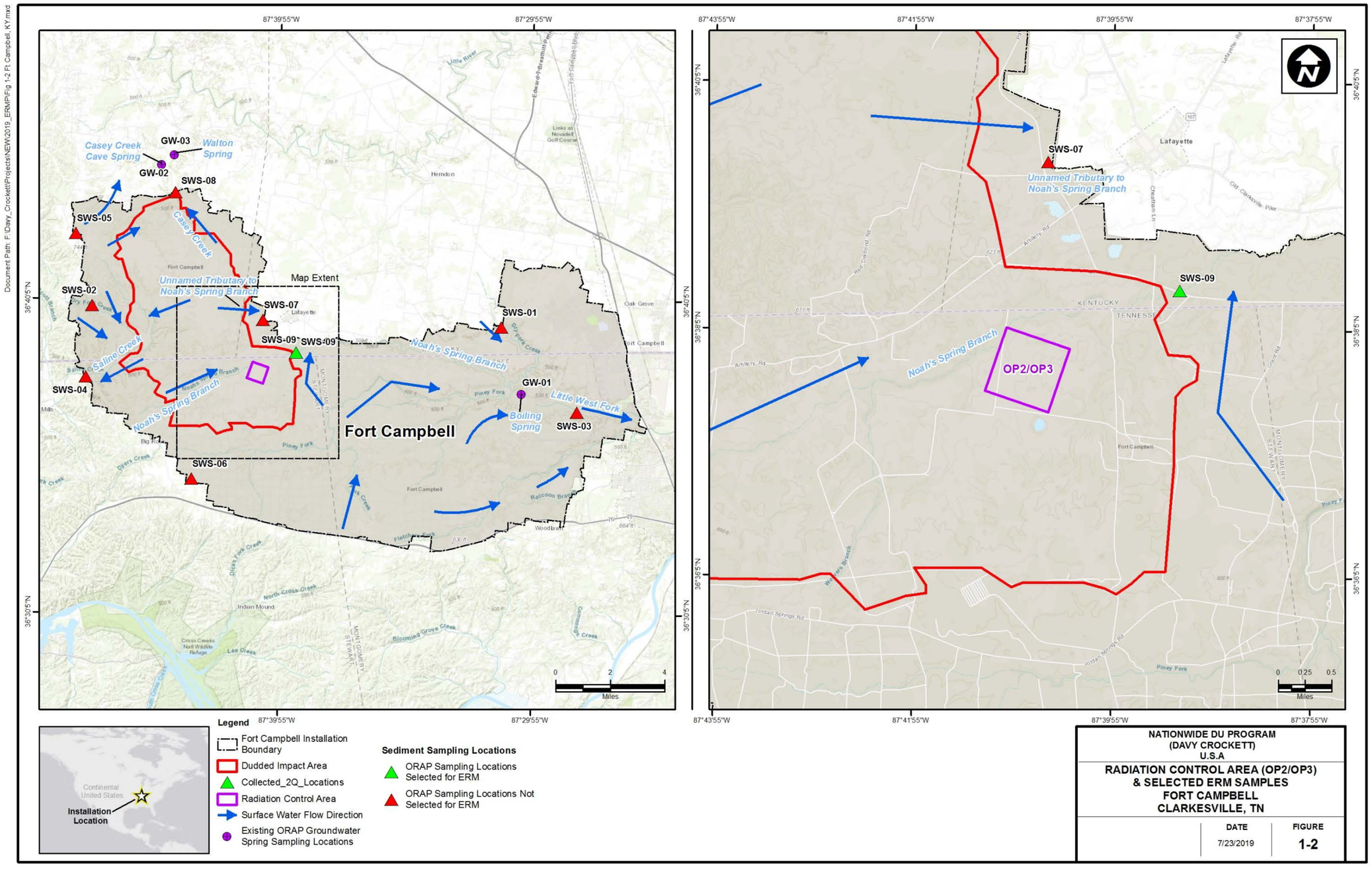

Figure 1-2. Radiation Control Area (OP2/OP3) and Selected ERM Sample Locations

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The majority of the Fort Campbell operational ranges were built in 1942, and the basic layout of the installation has not changed. Initially, the installation contained three impact areas (North Impact Area, South Impact Area, and Small Arms Range Impact Area); however, in the mid-1980s, two of the impact areas were merged into the North Impact Area to accommodate the Safety Danger Zone from an adjacent live-fire range. The Small Arms Impact Area remains unchanged and consists of training and maneuver areas. The majority of the live-fire ranges are oriented in a "wagon-wheel" around the Nondudded Impact Area; however, the dudded North Impact Area (Figure 1-1) contains multiple live-fire ranges (EA 2014).

In addition to these two impact areas, the installation contains 53 maneuver and training areas, 46 basic firing ranges, 4 landing/drop zones, 7 observation points, 1 demolition range, and 7 shoot houses. Fixed artillery firing points are located throughout 20 of the maneuver and training areas (EA 2014).

An Archives Search Report (ASR) (USACE 2010) confirmed the presence of one range where the Davy Crockett weapons system was used at Fort Campbell. The OP2/OP3 Impact Area or radiation control area (RCA) consists of 247 acres (Figure 1-2). The nearest normally occupied areas to the OP2/OP3 Impact Area RCA are located approximately 1.9 miles east to northeast of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the OP2/OP3 Impact Area; therefore, it is assumed that most, if not all, of the 130 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Campbell is located within the Interior Low Plateaus physiographic province and the Highland Rim surrounding the Nashville Basin. The section is also referred to as the Pennyroyal Plateau. The terrain is gently rolling, with a flat area along the eastern boundary and a steep, highly dissected, hilly area along the far western boundary. Regional relief is low to moderate with elevations of 400 to 700 feet. Bedrock is composed of limestone, chert, and shale and depths to bedrock range from 20 to approximately 100 feet below ground surface (bgs) (EA 2014).

Regional bedrock is flat-laying with a slight dip to the north, and exposed units typically consist of, from youngest to oldest, the Cretaceous Age Tuscaloosa Formation (Tuscaloosa Quartz Gravel) in the western highlands; Mississippian Age Saint Genevieve Limestone, exposed throughout a majority of Fort Campbell; and the Mississippian Age Saint Louis Limestone, which is only exposed where streams have eroded through the Saint Genevieve Limestone. Underlying the exposed geologic units is the Mississippian aged Warsaw Limestone, which consists of a predominant chert bed and the Devonian aged Chattanooga Shale. Limestone units in the region are characterized by karst geomorphology, including solution-enlarged sinkholes, caves, and springs. Although karst terrane and conduit flow occur throughout Fort Campbell, sinkholes are rare within the western portion of Fort Campbell, which is capped by the resistant Tuscaloosa

Gravel and includes the RCA location, and are more common eastward toward the Cantonment Area (EA 2014).

Groundwater flow beneath Fort Campbell consists of a semi-confined aquifer system within the Mississippian limestones overlain by a low-permeability ferrous clay matrix causing localized confinement and directing a majority of overland flow toward surface water bodies or into sinkholes. The major discharge of groundwater from the Mississippian limestones occurs through springs and seeps along deep stream channels. Historical and recent dye-tracer studies confirm that groundwater flows following solution-enlarged bedding planes and conduits are characterized by localized hydraulic gradients and discharges into surface water bodies or major springs, such as Boiling Spring (EA 2014).

Surface water at Fort Campbell is composed of both perennial and intermittent stream morphologies based mostly on the underlying geology. Most streams at higher elevations at Fort Campbell are losing streams, which do not flow during the dry season; streams at lower elevations gain flow from groundwater discharge from the karst aquifer. The streams surrounding the RCA are intermittent and do not flow during the dry season (EA 2014).

Primary watersheds at Fort Campbell include Casey Creek to the northwest, Saline Creek to the west, Noah's Spring Branch along the north-central and southwest, and Little West Fort Creek from the south and including the eastern portion of Fort Campbell. The Noah's Spring Branch watershed is approximately 53.2 square miles (USGS 1996). The RCA is drained to the northeast into Noah's Spring Branch by an unnamed tributary and Noah's Spring Branch (Figure 1-1). Noah's Spring Branch flows in a northeasterly direction, exits, and reenters the northern portion of the installation's western boundary. The creek eventually discharges (within the installation) into Little West Fork Creek (EA 2014). Little West Fork Creek eventually drains into the Red River, a major tributary to the Cumberland River, which discharges into the Ohio River. The Ohio River drains to the Mississippi River and ultimately the Gulf of Mexico.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the OP2/OP3 Impact Area RCA at Fort Campbell are as follows:

- ***Surface Water Use***—The Unnamed Tributary to Noah's Spring Branch and Noah's Spring Branch are not used for consumption of drinking water. Noah's Spring Branch downstream from the RCA is used for general recreation, livestock and wildlife watering, and irrigation (Potomac-Hudson Engineering, Inc. 2015). Noah's Spring Branch flows into Little West Fork Creek, which flows into the Red River, which is used by residents for drinking water consumption. Surface water surrounding Fort Campbell, including Noah's Spring Branch, Little West Fork Creek, Saline Creek, Casey Creek, and their tributaries, contains sensitive environments, habitats, and ecological receptors.
- ***Recreational Use***—The unnamed tributary to Noah's Spring Branch, which receives discharge from the OP2/OP3 Impact Area, is an intermittent stream (e.g., typically does not flow during the dry season). No known recreational activities occur in this intermittent channel; however, Noah's Spring Branch is a tributary of Little West Fork Creek. Recreational activities occurring within 15 miles of and downgradient from the RCA include boating, fishing, and swimming in the Little West Fork Creek and its tributaries.
- ***Sensitive Environments***—Sensitive environments on and around Fort Campbell include wetland and riparian habitats, which are found directly off Fort Campbell and provide habitats for three federally listed threatened and endangered species (Indiana bat, gray bat, and northern

long-eared bat). Although the OP2/OP3 Impact Area RCA has not been surveyed for the presence or absence of these species, all three species may forage along Noah's Spring Branch (U.S. Army 2015).

- ***Habitat***—The habitat at the OP2/OP3 Impact Area RCA is primarily grassland with a small, intermittent stream (Noah's Spring Branch) that occasionally flows through the RCA. The areas surrounding Fort Campbell consist of the following habitats: grasslands, wetlands, and forested riparian areas. The habitat types that surround Fort Campbell are occupied by the listed threatened and endangered species, farmlands, and some urban development. Agriculture is the predominant land use in Montgomery County (Tennessee) to the south of Fort Campbell and in a portion of Christian County (Kentucky) at the northern boundary of the installation. There is a substantial amount of development in the areas east south of Fort Campbell, particularly within the city limits of Clarksville (Tennessee), Oak Grove (Kentucky), and Hopkinsville (Kentucky), and along U.S. Route 41A, which connects them. Residential and commercial development is concentrated immediately east of the installation on the east side of U.S. Route 41A just north of the Kentucky/Tennessee state line in Oak Grove (U.S Army 2009).
- ***Ecological Receptors***—Three threatened and endangered species have been identified or occasionally observed on Fort Campbell: the endangered Gray bat, the endangered Indiana bat, and threatened northern long-eared bat. Although their presence has not been confirmed at the OP2/OP3 Impact Area RCA, these ecological receptors may forage along Noah's Spring Branch. Habitat for these receptors is present along Noah's Spring Branch and downgradient north of the Noah's Spring Branch watershed. The American bald eagle, a formerly listed species, is occasionally observed on Fort Campbell in the winter. The habitats preferred by the American bald eagle, hardwood forest and open water, are present downgradient from the OP2/OP3 Impact Area RCA and Noah's Spring Branch watershed. In addition to the ecological receptors listed above, Fort Campbell is also home to 21 other wildlife species listed as threatened or endangered by Kentucky and/or Tennessee and 23 species of special concern, in need of management, rare, or declining by one or both states (EA 2013).
- ***Groundwater Use***—The primary source of drinking water used at Fort Campbell originates from Boiling Spring, which receives groundwater from the Boiling Spring groundwater basin. This basin covers 50 square miles on Fort Campbell and is located in the Little West Fork Creek watershed. Groundwater within 4 miles downgradient from Fort Campbell is used for domestic drinking water supplies. There are numerous domestic wells surrounding Fort Campbell downgradient from the RCA that rely on drinking water from the shallow unconsolidated alluvial aquifer.

Potential human receptors include those within Fort Campbell relying on potential public and private wells within 4 miles downgradient from the RCA for potable water. Ecological receptors include sensitive environments (e.g., wetlands and riparian habitat providing habitat for threatened and endangered species).

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the OP2/OP3 Impact Area RCA at Fort Campbell are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of one sample downstream from the RCA (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling location at the OP2/OP3 Impact Area RCA was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-09***—The selected sampling point is located in Noah's Spring Branch, downstream from the Dudded Impact Area and RCA along the northern installation boundary. Sampling of SWS-09 will need to be set up on high ground in order to avoid problems with flooding at this location. The location was moved slightly from the Operational Range Assessment Program (ORAP) Phase II location for easier access.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the OP2/OP3 Impact Area RCA based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-03***—The ORAP sampling point is located on Little West Fork Creek on the eastern portion of Fort Campbell. The location is downstream from the Non-Dudded Impact Area and upstream of the wastewater treatment plant in a perennial creek, but is not downstream from the Dudded Impact Area and RCA.
- ***SWS-04***—The ORAP sampling point is located in Saline Creek along the western boundary of Fort Campbell. This perennial creek location is downstream from portions of the Dudded Impact Area but does not receive drainage from the RCA.
- ***SWS-07***—The ORAP sampling point is located in an unnamed tributary to Noah's Spring Branch, which flows north of Fort Campbell upstream of the discharge to Noah's Spring Branch. This intermittent creek location is downstream from portions of the Dudded Impact Area, but does not receive drainage from the RCA.
- ***SWS-08***—The ORAP sampling point is located in Casey Creek along the northwestern boundary of Fort Campbell. This intermittent creek location is downstream from portions of the Dudded Impact Area but does not receive drainage from the RCA.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry).

Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The selected downstream sampling location, SWS-09, for the environmental radiation monitoring (ERM) along with additional locations were sampled during the ORAP Phase II assessment in 2013 and 2014 and analyzed for uranium in surface water and sediment (EA 2014). The U-238/ U-234 activity ratios from the 2013 and 2014 sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2013 and 2014 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range*
SWS-03 (Little West Fork Creek)	4	ND-0.802
SWS-04 (Saline Creek)	4	ND-0.079
SWS-07 (Downstream, Unnamed Tributary to Noah's Spring Branch)	4	ND
SWS-08 (Casey Creek)	4	ND-0.183
SWS-09 (Downstream, Noah's Spring Branch)	4	ND-0.639

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2013 and 2014 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range*
SWS-03 (Little West Fork Creek)	3	0.751-1.124
SWS-04 (Saline Creek)	3	0.670-0.735
SWS-07 (Downstream, Unnamed Tributary to Noah's Spring Branch)	3	0.925-1.197
SWS-08 (Casey Creek)	3	0.717-1.011
SWS-09 (Downstream, Noah's Spring Branch)	3	0.953-1.120

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Fort Campbell, Kentucky, Annex 4 (ML16265A238) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, SWS-09, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Campbell are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of

Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-09	5/26/2017	0.74 +/- 0.37
SWS-09	8/30/2017	ND
SWS-09	11/30/2017	0.20 +/- 0.17
SWS-09	3/7/2018	ND
SWS-09	5/31/2018	0.63 +/- 0.68
SWS-09	9/12/2018	ND
SWS-09	11/28/2018	0.73 +/- 0.63

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-09	5/26/2017	0.94 +/- 0.31
SWS-09	8/30/2017	0.95 +/- 0.24
SWS-09	11/30/2017	0.75 +/- 0.17
SWS-09	3/7/2018	1.1 +/- 0.3
SWS-09	5/31/2018	0.95 +/- 0.26
SWS-09	9/12/2018	0.99 +/- 0.21
SWS-09	11/28/2018	0.87 +/- 0.21

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at Fort Campbell.

2.2 GROUNDWATER

Groundwater monitoring wells were not sampled for uranium during the ORAP Phase II assessment in 2013 and 2014. As part of the ORAP Phase II assessment, groundwater samples were collected from one spring location located on Fort Campbell (Boiling Spring) and two locations located north of Fort Campbell (Casey Creek Cave Spring and Walton Spring). Sediment samples were collected from each of the spring locations north of Fort Campbell. The U-238/U-234 activity ratios from the sampling events are presented in Table 2-5. The groundwater spring sampling locations are shown in Figure 1-2. Presently, no groundwater monitoring wells are located at or near the RCA. Domestic wells are present more than 2 miles downgradient from (northeast of) the RCA.

Table 2-5. U-238/U-234 Activity Ratios for Groundwater Spring and Groundwater Spring Sediment Samples

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Groundwater Spring Samples		
GW-01 (Boiling Spring)	2	0.485-0.981
GW-02 (Casey Creek Cave Spring)	2	ND-1.09
GW-03 (Walton Spring)	2	ND-0.878
Groundwater Spring Sediment Samples		
GW-01 (Boiling Spring)	2	Not collected
GW-02 (Casey Creek Cave Spring)	2	0.796-1.19
GW-03 (Walton Spring)	2	1.03-1.09

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU.

ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Presently, no groundwater monitoring wells are located at or near the RCA. The groundwater spring locations, GW-01, GW-02, and GW-03, were located on the eastern portion of Fort Campbell and north of Fort Campbell. These locations are not downstream from the Dudded Impact Area or the RCA. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Campbell.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Campbell does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Campbell will be coordinated with the Fort Campbell Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (130 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Campbell RCA

Parameter		Default Value	Fort Campbell OP2/OP3 Impact Area	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	1.28×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC Materials License. = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	1.17×10^{-3}	
	U-238	N/A	0.19	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 17 to 22 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt (Soil is silt loam from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Contaminated zone b parameter		5.3	5.3	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Average annual wind speed (m/s)		2.0	8.2	**www.usa.com** for Fort Campbell, KY
Precipitation rate (annual rainfall) (m/y)		1.0	1.3	**www.usa.com** for Fort Campbell, KY
Saturated Zone				
Saturated zone total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Saturated zone b parameter		5.3	5.3	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Unsaturated Zone				
Unsaturated zone 1, thickness (m)		4.0	5.2	Depth to groundwater is generally 17 to 22 ft bgs
Unsaturated zone 1, total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	5.3	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Campbell RCA

RCA Layout Parameter	Fort Campbell OP2/OP3 Impact Area			
Distance to nearest normally occupied area (m)	2,700			
Bearing of X axis (degrees)	135 (northeast)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	3800	3832
Leafy vegetables plot	500	531.25	3834	3866
Pasture, silage growing area	500	600	4016	4116
Grain fields	500	600	3866	3966
Dwelling site	500	531.25	3700	3732
Surface-water body	500	800	4116	4416
Primary Contamination Parameter				
Length parallel to aquifer flow*	732			
Atmospheric Transport Parameter				
Meteorological STAR file	KY_PADUCAH.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	2,700			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	3,116			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Campbell does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Campbell Range OP2/OP3	0.022	7.2×10^{-3}

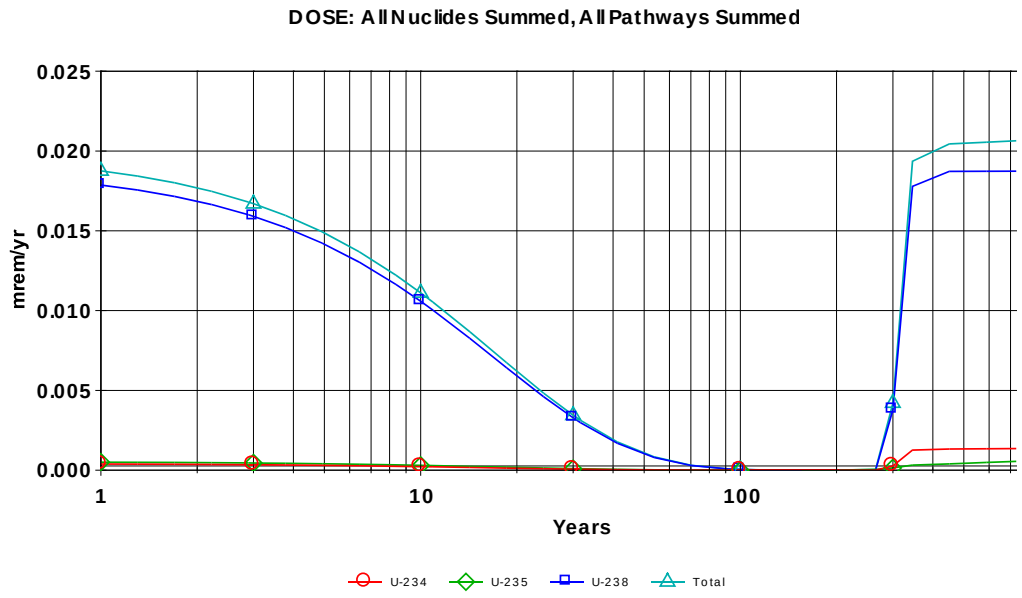
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

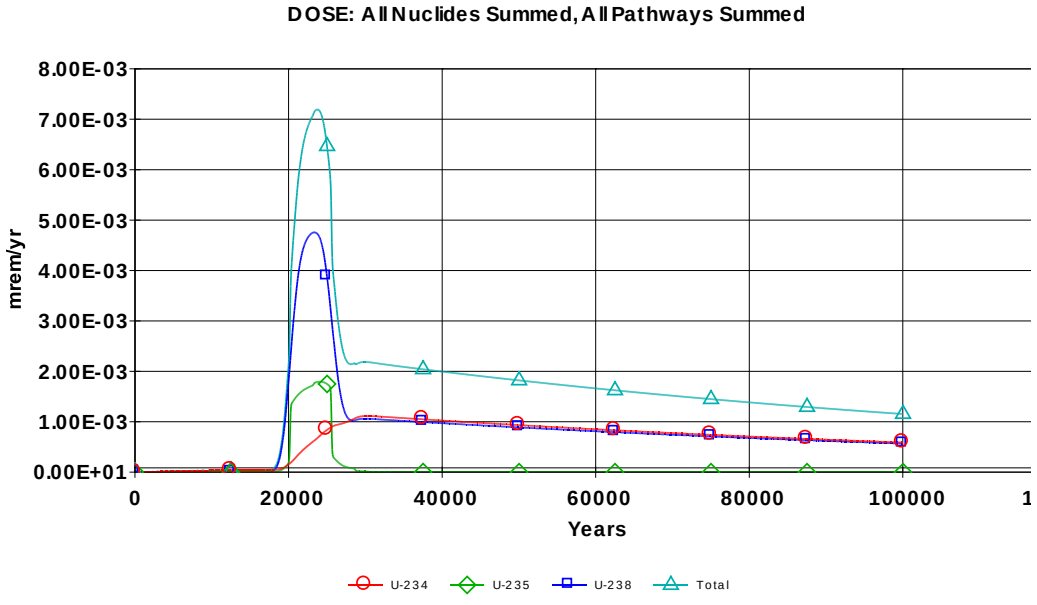
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Campbell Range OP2/OP3

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4]	
				(Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT CARSON, COLORADO ANNEX 5

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
CD	Compact Disk
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance
WWII	World War II

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Carson, Colorado, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Carson, Colorado, Annex 5 (ML16265A239) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Carson. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream **(SWS-02)** from the Range 141 RCA and **(SWS-03)** from the Battalion Field Training Area RCA, as shown on Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Fort Carson is a 138,275-acre installation located in potions of El Paso, Pueblo, and Fremont Counties in Colorado, adjacent to Colorado Springs, Colorado (Figure 1-1). The installation is predominantly operational with the exception of 8,438 acres with uses such as military housing. In Fort Carson, there are 229 currently operational ranges, which include training ranges, multi-use ranges, firing ranges, impact areas, and demolition ranges (EA 2012).

In 1942, at the advent of the U.S. involvement in World War II (WWII), the city of Colorado Springs bought property adjacent to the city and donated it to the War Department. The formation of a military facility began swiftly on the newly donated property in preparation for new troops. Camp Carson, named after Kit Carson, housed more than 125 new military units and more than 100 transferred units during WWII along with a prisoner-of-war camp (EA 2012).

After WWII, Camp Carson diminished in personnel size but was still active as a survival school until the advent of the Korean War. At this time, there was an increase in military use of the camp.

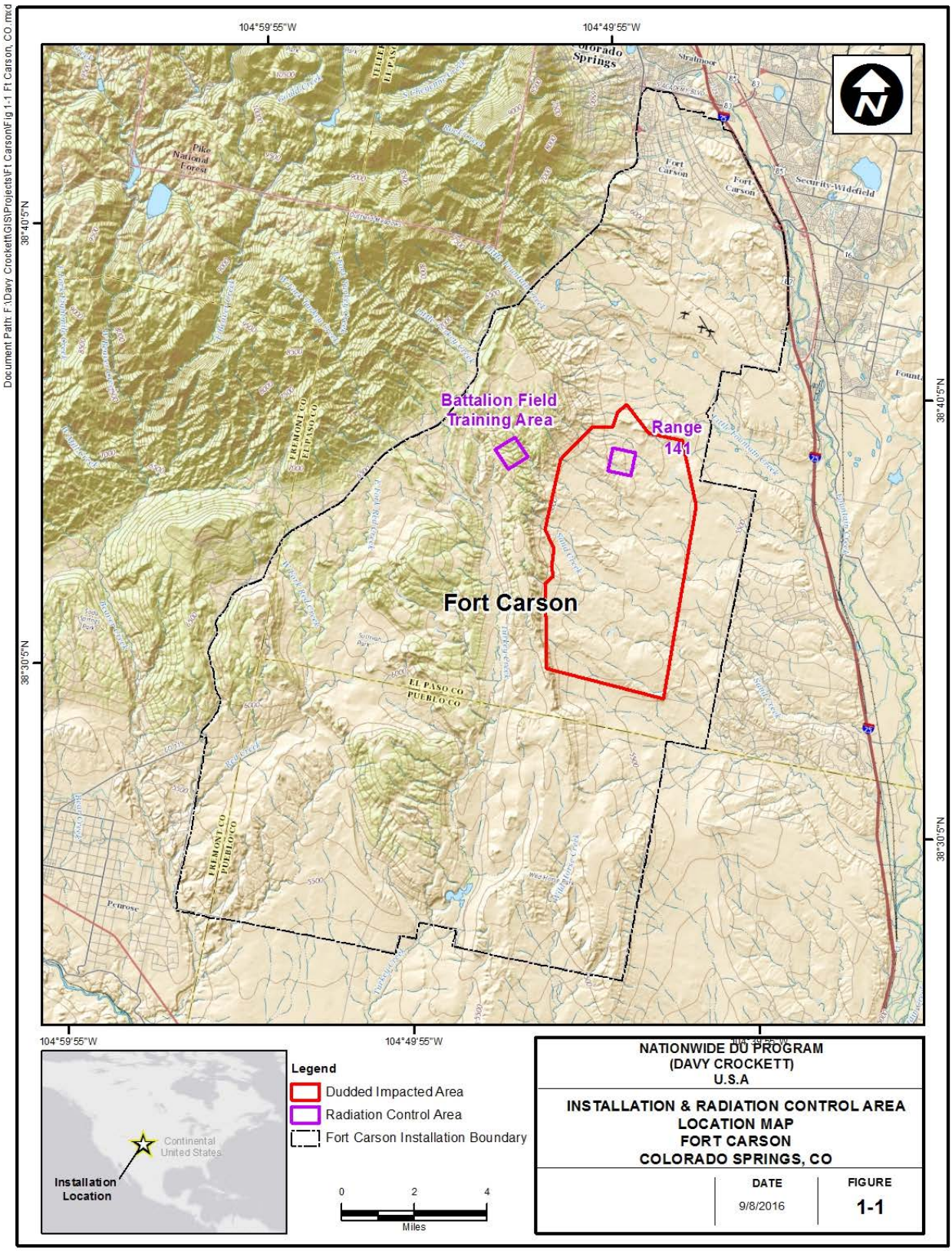

Figure 1-1. Installation and Radiation Control Area Location Map

In 1954, Camp Carson was redesignated to Fort Carson. Following the redesignation in the 1960s, Fort Carson was expanded to its current extent due to the needs of its mechanized units. An addition to Fort Carson, the Pinon Canyon Maneuver Site, was purchased in 1983. This 237,000-acre property located 150 miles to the southeast is utilized by Fort Carson for large maneuver training. Fort Carson and Pinon Canyon Maneuver Site are still in use today (Fort Carson 2013).

An Archives Search Report (ASR) (USACE 2008) confirmed the presence of ranges where the Davy Crockett weapons system was used at Fort Carson. Range 141 and the Battalion Field Training Area are each 247–acre radiation control areas (RCAs) (Figure 1-2). The nearest normally occupied areas to the Range 141 and the Battalion Field Training Area RCAs are located approximately 3.6 miles north and 2 miles west of the RCAs, respectively.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Range 141 or the Battalion Field Training Area; therefore, it is assumed that most, if not all, of the 270 kilograms (kg) of DU from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Fort Carson is located at the western edge of the Colorado Piedmont section of the Great Plains Physiographic Province, at its border with the Southern Rocky Mountain Physiographic Province (USACHPPM 2007). The western half of the installation lies within the Southern Rocky Mountains and is characterized by deep canyons and hills. The northern and eastern parts lie within the Colorado Piedmont section and are characterized by bisected plains and terraces (EA 2012).

Streams draining the operational ranges at Fort Carson consist of ephemeral/intermittent streams, with limited to no flow during most of the year. However, several streams have on-installation reaches that support limited perennial flows (<0.5 cubic feet per second [cfs]) as a result of spring discharge. Creeks located in the western and southeastern parts of the installation are within the Upper Arkansas River watershed and are tributaries to the Arkansas River. Creeks located on the eastern parts of the installation are located within the Fountain Creek watershed and are tributaries to Fountain Creek, which is itself a tributary to the Arkansas River. Range 141 and the Battalion Field Training Area are encompassed in the Fountain Creek watershed (Figure 1-2). Within the watershed, Sand Creek and Unnamed Creek are the main course of drainage from the RCAs. Both drainages are likely spring fed as observed from site reconnaissance performed for the Operational Range Assessment Program (ORAP). Sand Creek was observed to have periods of time with no flow (EA 2011, EA 2012).

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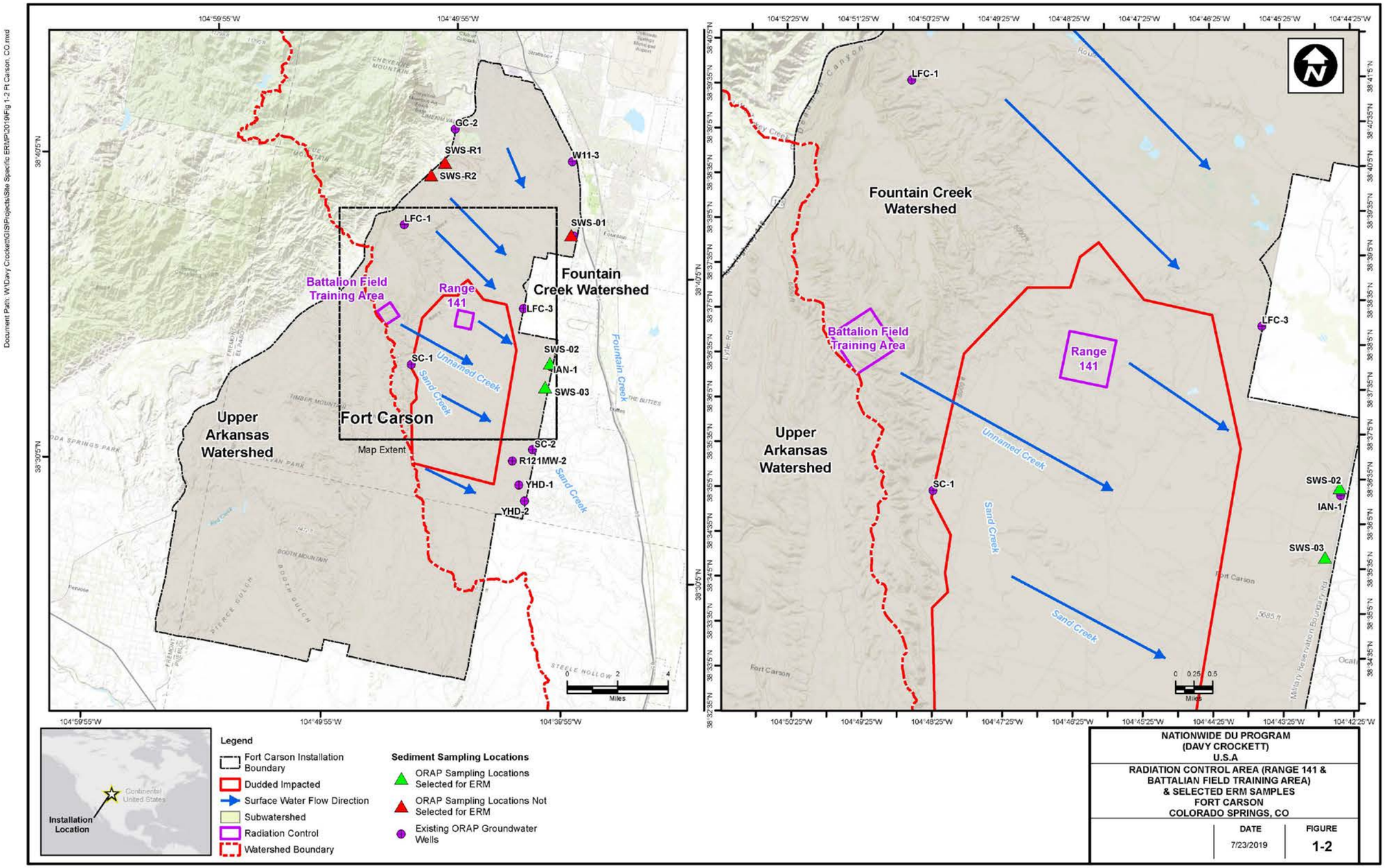

Figure 1-2. Radiation Control Area (Range 141 and Battalion Field Training Area) and Selected ERM Samples

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The geology at Fort Carson's eastern region is underlain by east dipping Upper Cretaceous sedimentary strata and Quaternary alluvium. Groundwater in the bedrock aquifer follows the dip of the sedimentary strata to the southeast. Two major bedrock aquifer systems, the Dakota-Purgatoire aquifer and the Fountain aquifer, occur at Fort Carson. The depth of the aquifers reaches their maximum extents on the eastern boundary of Fort Carson with potential depths of 1,800 and 2,000 feet below ground surface (bgs), respectively. The depth to groundwater in the bedrock aquifers ranges from 8 to 460 feet bgs for the Dakota-Purgatoire aquifer and 20 to 30 feet bgs for the Fountain Creek aquifer (EA 2011, EA 2012).

The Quaternary alluvial aquifers include Pleistocene alluvial deposits and the Holocene Piney Creek Alluvium. The Pleistocene aquifers are generally thin, of limited areal extent, and only saturated part of the year. The alluvium aquifers can be encountered from 3 to 53 feet bgs. In addition, the depth to water has been seen to fluctuate with the seasons, leaving wells dry. Of the alluvium aquifers, the Piney Creek Alluvium is seen as an important aquifer at the installation because it possesses sufficient permeability to transmit groundwater to the surface streams. Groundwater movement through the alluvial aquifers in the vicinity of the RCAs is to the east with discharge into a variety of surface water bodies. Seepage velocity from the alluvial aquifers can vary from 0.75 feet per day to 150 feet per year with a hydraulic conductivity of 0.0002 feet per day to 7.5 feet per day (USACHPPM 2007, EA 2011, EA 2012).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for Range 141 and the Battalion Field Training Area at Fort Carson are as follows:

- ***Surface Water Use***—No known use of surface water exists for consumption of drinking water downstream from the RCAs.
- ***Recreational Use***—Fountain Creek, located downstream from on-range source areas, is not used heavily for recreational activities.
- ***Sensitive Environments***—Wetlands extend off the operational range area and are also located along surface water bodies downstream from the installation, including along Fountain Creek and its tributaries.
- ***Habitat***—The installation and its surrounding areas consist predominantly of grasslands, scrublands, and forest/woodlands. Fort Carson is characterized by openness and generally treeless terrain dominated by shortgrass prairie. Approximately 48 percent of Fort Carson is composed of grasslands, along with a variety of shrubs, located primarily on the eastern, east-central, and southwestern portions of the installation. Scrublands cover approximately 15 percent and can be found throughout the installation and along the major drainages. The remaining 37 percent of the installation consists of forest/woodlands, which are located primarily on the western portion of the installation.
- ***Ecological Receptors***—Two Federal and/or state-listed threatened fish species occur in Fountain Creek watershed: the greenback cutthroat trout and the Arkansas darter. The Arkansas darter has been identified in sections of Fountain Creek downstream from Fort Carson.

- ***Groundwater Use***—Groundwater is used for potable private/domestic and public water supply use. Receptors associated with these wells, located within 4 miles downgradient from source areas, are mostly east of Fort Carson in areas along Fountain Creek. Numerous private/domestic wells are screened within the alluvium of the surficial aquifer, including a well used by a private water company (Wigwam Mutual Water) that provides water to residents in local developments.

Potential human receptors include those within Fort Carson and nearby residents to the southeast relying on potential public and private wells within 4 miles downgradient from the RCA for potable water. Ecological receptors include sensitive threatened species environments (e.g., riverine environments and the greenback cutthroat trout).

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for Range 141 and the Battalion Field Training Area at Fort Carson are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of two samples from locations downstream from the RCAs near the Fort Carson installation boundary (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling locations at Range 141 and the Battalion Field Training Area were selected based on the surface water hydrology downstream from the RCAs, the location of the RCAs, and the potential for DU contribution, and are located as follows:

- ***SWS-02***—The selected sampling point is located on the Sand Canyon, downstream from the Range 141 RCA at the installation's eastern boundary and upstream of the confluence between the Sand Canyon and Fountain Creek.

- ***SWS-03***—The selected sampling point is located on the unnamed creek, downstream from the Battalion Field Training Area RCA at the installation's eastern boundary and upstream of the confluence between the Unnamed Creek and Fountain Creek.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the Range 141 and the Battalion Field Training Area RCAs based on surface water hydrology and the potential for DU contribution, and are located as follows:

- ***SWS-01***—The ORAP sampling point is located in the northern groundwater region approximately 7 miles the north from the RCAs. SWS-01 is not downstream from either of the RCAs.
- ***SWS-R1***—The ORAP sampling point is a background/reference sampling location and is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.
- ***SWS-R2***—The ORAP sampling point is a background/reference sampling location and is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 based on alpha spectrometry. Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA

indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.1 (Definitions) and then to determine if the samples are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than weight percent U-235).

The selected downstream sampling locations, SWS-02 and SWS-03, for the environmental radiation monitoring (ERM) along with additional locations were sampled during the ORAP Phase II assessment in 2011 and analyzed for uranium in surface water and sediment (EA 2012). The U-238/U-234 activity ratios from the 2011 sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2011 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
SWS-01, SWS-02, SWS-03	8	0.6-0.8
Reference (SWS-R1, SWS-R2)	2	0.3 -0.9

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2011 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
SWS-01, SWS-02, SWS-03	8	0.9-1.2
Reference (SWS-R1, SWS-R2)	6	0.8-0.9

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Fort Carson, Colorado, Annex 5 (ML16265A239) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, SWS-02 and SWS-03, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Carson are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Carson.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-02	5/24/2017	0.66 +/- 0.12
SWS-03	5/24/2017	0.66 +/- 0.14
SWS-02	9/14/2017	--- +/- ---
SWS-03	9/14/2017	0.70 +/- 0.09
SWS-02	12/7/2017	0.62 +/- 0.08
SWS-03	12/7/2017	0.63 +/- 0.1
SWS-02	3/15/2018	--- +/- ---
SWS-03	3/15/2018	0.69 +/- 0.09
SWS-02	5/24/2018	--- +/- ---
SWS-03	5/24/2018	0.63 +/- 0.1
SWS-02	9/4/2018	0.67 +/- 0.09
SWS-03	9/4/2018	0.68 +/- 0.11
SWS-02	11/28/2018	--- +/- ---
SWS-03	11/28/2018	0.65 +/- 0.11

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
--- +/--- – Indicates a surface water sample was not collected because water was not present during sampling.

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-02	5/24/2017	0.75 +/- 0.17
SWS-03	5/24/2017	0.71 +/- 0.17
SWS-02	9/14/2017	0.93 +/- 0.22
SWS-03	9/14/2017	0.91 +/- 0.12
SWS-02	12/7/2017	0.91 +/- 0.21
SWS-03	12/7/2017	0.76 +/- 0.13
SWS-02	3/15/2018	0.97 +/- 0.22
SWS-03	3/15/2018	0.89 +/- 0.17
SWS-02	5/24/2018	1.0 +/- 0.3
SWS-03	5/24/2018	0.87 +/- 0.16
SWS-02	9/4/2018	0.82 +/- 0.19
SWS-03	9/4/2018	0.94 +/- 0.19
SWS-02	11/28/2018	0.89 +/- 0.2
SWS-03	11/28/2018	0.90 +/- 0.16

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment in 2011 were analyzed for uranium (EA 2012). The U-238/U-234 activity ratios from the June 2011 sampling event are presented in Table 2-5. The existing groundwater monitoring wells are shown in Figure 1-2.

Table 2-5. U-238/U-234 Activity Ratios for Groundwater Samples Collected During the 2011 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio* (unitless)
IAN-1	1	0.5
Upgradient	1	0.8

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

Presently, no groundwater monitoring wells are located at or near the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Carson.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Range 141 and the Battalion Field Training Area do not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Carson will be coordinated with the Fort Carson Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample locations. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (270 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Carson RCAs

Parameter		Default Value	Fort Carson Range 141 and Battalion Field Training Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	2.66×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC Materials License. = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	2.43×10^{-3}	
	U-238	N/A	0.4	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 3 to 53 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.39	RESRAD Manual (DOE 2001) Table E-8 for Coarse Sand (Soil is cobbly sandy loam from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	1090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Contaminated zone b parameter		5.3	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Average annual wind speed (m/s)		2.0	9.2	**www.usa.com** for Fort Carson, CO
Precipitation rate (annual rainfall) (m/y)		1.0	0.49	**www.usa.com** for Fort Carson, CO
Saturated Zone				
Density of saturated zone (g/cm^3)		1.5	1.5	Assumed same as contaminated zone density
Saturated zone total porosity		0.4	0.39	RESRAD Manual (DOE 2001) Table E-8 for Coarse Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual (DOE 2001) Table E-8 for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	1090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Saturated zone b parameter		5.3	4.9	RESRAD Manual (DOE 2001) Table E.2 for Sandy Loam
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual (DOE 2001) Table E-8 for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual (DOE 2001) Table E-8 for Coarse Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.9	RESRAD Manual (DOE 2001) Table E.2 for Sandy Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	1090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Carson RCAs

RCA Layout Parameter	Range 141				Battalion Field Training Range			
Distance to nearest normally occupied area (m)	5,800				3,200			
Bearing of X axis (degrees)	90 (north)				0 (west)			
X dimension of primary contamination (m)	1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	6,900	6,932	500	531.25	4,300	4,332
Leafy vegetables plot	500	531.25	6,934	6,966	500	531.25	4,334	4,366
Pasture, silage growing area	500	600	7,116	7,216	500	600	4,516	4,616
Grain fields	500	600	6,966	7,066	500	600	4,366	4,466
Dwelling site	500	531.25	6,800	6,832	500	531.25	4,200	4,232
Surface-water body	500	800	7,216	7,516	500	800	4,616	4,916
Primary Contamination Parameter								
Length parallel to aquifer flow*	325				325			
Atmospheric Transport Parameter								
Meteorological STAR file	CO_COLORADO_SPRINGS.str				CO_COLORADO_SPRINGS.str			
Groundwater Transport Parameter								
Distance to well (parallel to aquifer flow) (m)	5,800				3,200			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	6,216				3,616			
Distance to well (perpendicular to aquifer flow) (m)	0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	270				180			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Carson does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Carson Range 141	0.046	0.030
Fort Carson Battalion Field Training Range	0.046	0.037

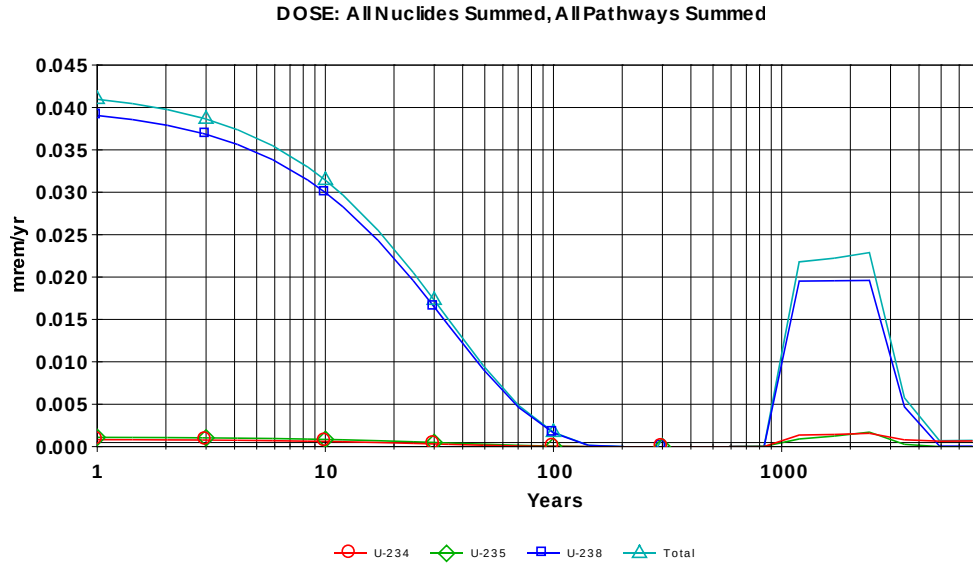
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

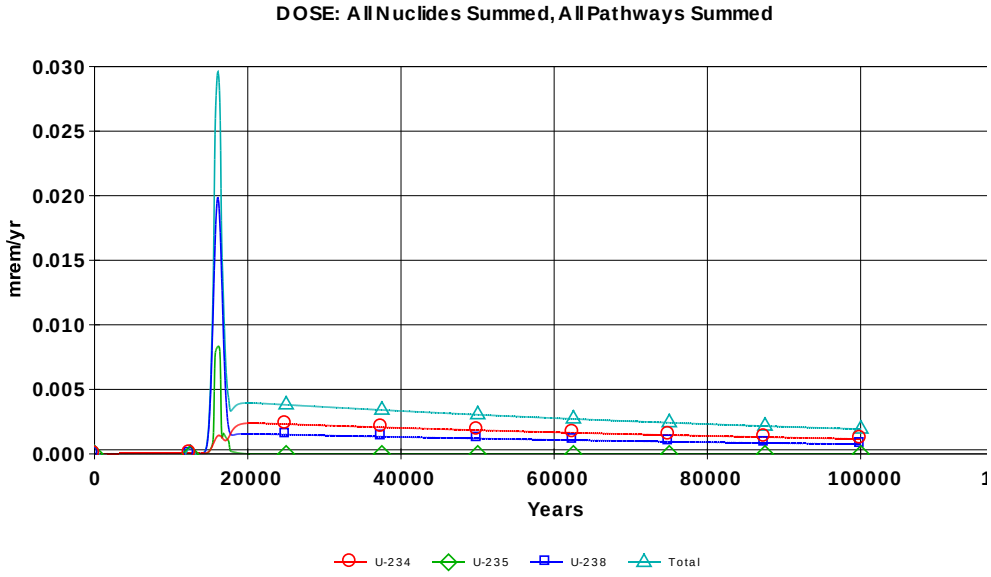
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Carson Range 141

RCA Onsite (RESRAD)

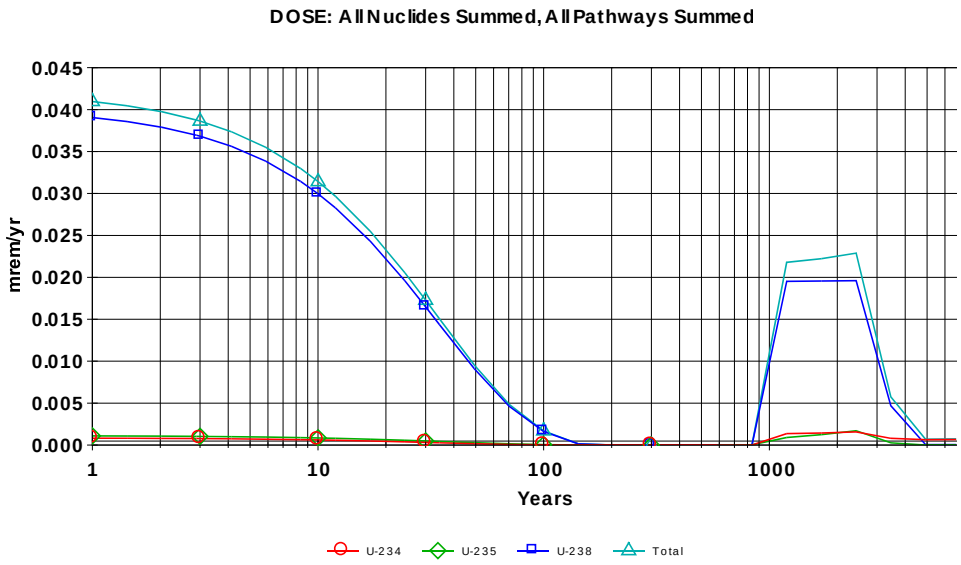


RCA Offsite (RESRAD-OFFSITE)

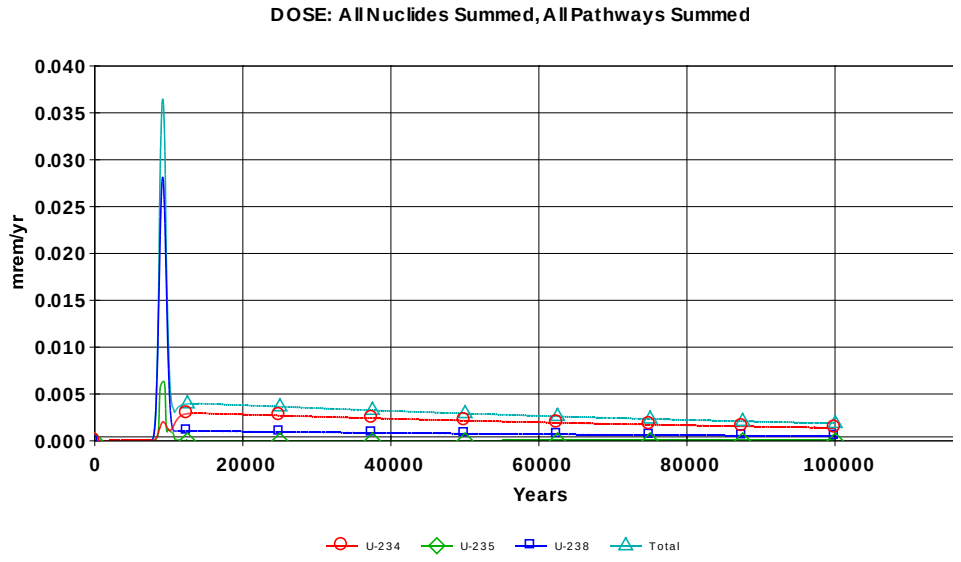


Fort Carson Battalion Field Training Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT EISENHOWER, GEORGIA ANNEX 6

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
2405 Gun Shed Road, Fort Sam Houston, Texas 78234-1223

Submitted To:

U.S. NUCLEAR REGULATORY COMMISSION
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11545 Rockville Pike, Two White Flint North, Rockville, Maryland 20852-2738

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ACRONYMS AND ABBREVIATIONS

AIT	Advanced Individual Training
ASR	Archives Search Report
bgs	Below Ground Surface
CFR	Code of Federal Regulations
CD	Compact Disk
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to Fort Eisenhower, Georgia, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Gordon, Georgia, Annex 6 (ML21165A013) (U.S. Army 2020a) and documents the Installation name change from Fort Gordon, Georgia, to Fort Eisenhower, Georgia, on October 27, 2023.

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Eisenhower, specifically Range E. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream (**Gut**) from the Range E RCA, as shown in Figure 1-2, based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Eisenhower is a 55,600-acre U.S. Army installation located about 9 miles southwest of downtown Augusta in east central Georgia (Figure 1-1). The entire installation is operational, and the operational range is southwest of the Cantonment Area where the vast majority of buildings, roads, and vehicles are located. Approximately 50,000 acres (90 percent) of Fort Eisenhower are used for training missions. Impact areas occupy approximately 13,000 acres and on-post maneuver and training areas (TAs) occupy approximately 37,000 acres, for a combined 90 percent of the installation.

The installation was originally established as Camp Gordon in 1941. During World War II, Camp Gordon served as a training base for Infantry, Mechanized Infantry, Armored Calvary, and Armor Divisions, and was home to the southeastern signal school. In 1948, Camp Gordon became home to the Signal Corps Training Center that moved from Fort Monmouth, New Jersey. The installation became a permanent military installation in 1956 and was renamed as "Fort Gordon." A U.S. Army Training Center (Basic) was activated at the installation in 1957, and the installation also provided Advanced Individual Training (AIT) for soldiers. Fort Gordon was re-designated as the "U.S. Army Signal Center and Fort Gordon" in 1974, and as the "U.S. Army Cyber Center of Excellence and Fort Gordon" in 2014. In 2023, Fort Gordon was renamed Fort Eisenhower.

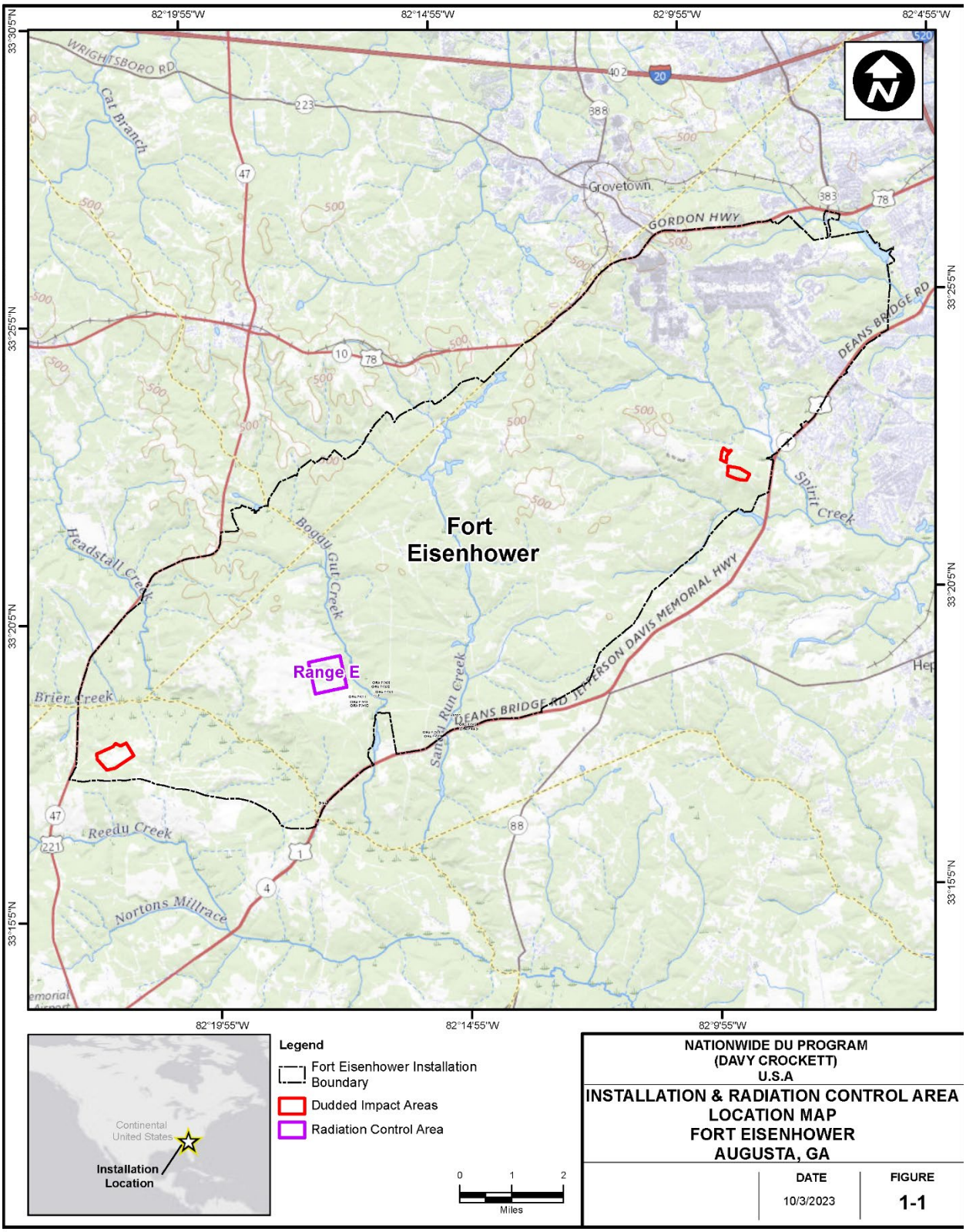

Figure 1-1. Installation and Radiation Control Area Location Map

An Archives Search Report (ASR) (USACE 2009) confirmed the presence of one range where the Davy Crockett weapons system was used at Fort Eisenhower. Range E or the radiation control area (RCA) consists of 247 acres (Figure 1-2). The nearest normally occupied area to the RCA is a residence, which is located approximately 1.5 miles southeast of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968.

These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly TA), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the RCA; therefore, it is assumed that most, if not all, of the 30 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

From a topography standpoint, Fort Eisenhower and the surrounding area are located along the fall line between the Lower Piedmont and Upper Coastal Plain physiographic provinces (USACHPPM 2008). The on- and off-range topography of the area consists primarily of gentle undulating sand hills, with areas of steep slopes and bluffs adjacent to some of the streams. Soils are dominantly sandy and very acidic, having been derived from marine sands, loams, and clay. The surface and subsurface soil drainage is high.

The geology of Fort Eisenhower consists of Coastal Plain sediments overlying Pre-Cambrian metamorphic and igneous basement rocks (USACHPPM 2008). The Coastal Plain sediments are essentially a wedge of intermixed sedimentary deposits that dip and thicken to the southeast. The lithology of the sediment is variable, with sand and gravel predominating; clay layers are present but discontinuous. The Coastal Plain sediments are heterogeneous, porous, and permeable. A significant structural feature in the area is the Belair Fault. It is oriented northeast to southwest and runs through both cantonment and operational range areas.

A shallow unconfined aquifer exists at some locations under Fort Eisenhower. The water table of this aquifer is generally 10 to 25 feet below ground surface (bgs) and mimics the land surface topography (USACHPPM 2008). Shallow groundwater discharge occurs where streams intersect the water table. Recharge to the shallow aquifer is from precipitation. A deeper, locally confined to semi-confined regional Cretaceous aquifer system exists in the Fort Eisenhower area. It is about 50 to 200 feet bgs. The aquitards that separate the aquifers are leaky. Thus, some of the recharge to the deeper aquifers is from the aquifer above. Regional groundwater flow for the Cretaceous aquifers is southeast toward the Savannah River. Fort Eisenhower sits on top of the recharge zone for the underlying Cretaceous drinking water aquifers.

Surface water drainage in the area is generally southeasterly, toward the Savannah River. The main surface water drainages include Brier, Boggy Gut, Sandy Run, South Prong, Spirit, and Butler Creeks. Most stream bottoms have associated wetlands. Ponds and reservoirs are also present in most drainage networks.

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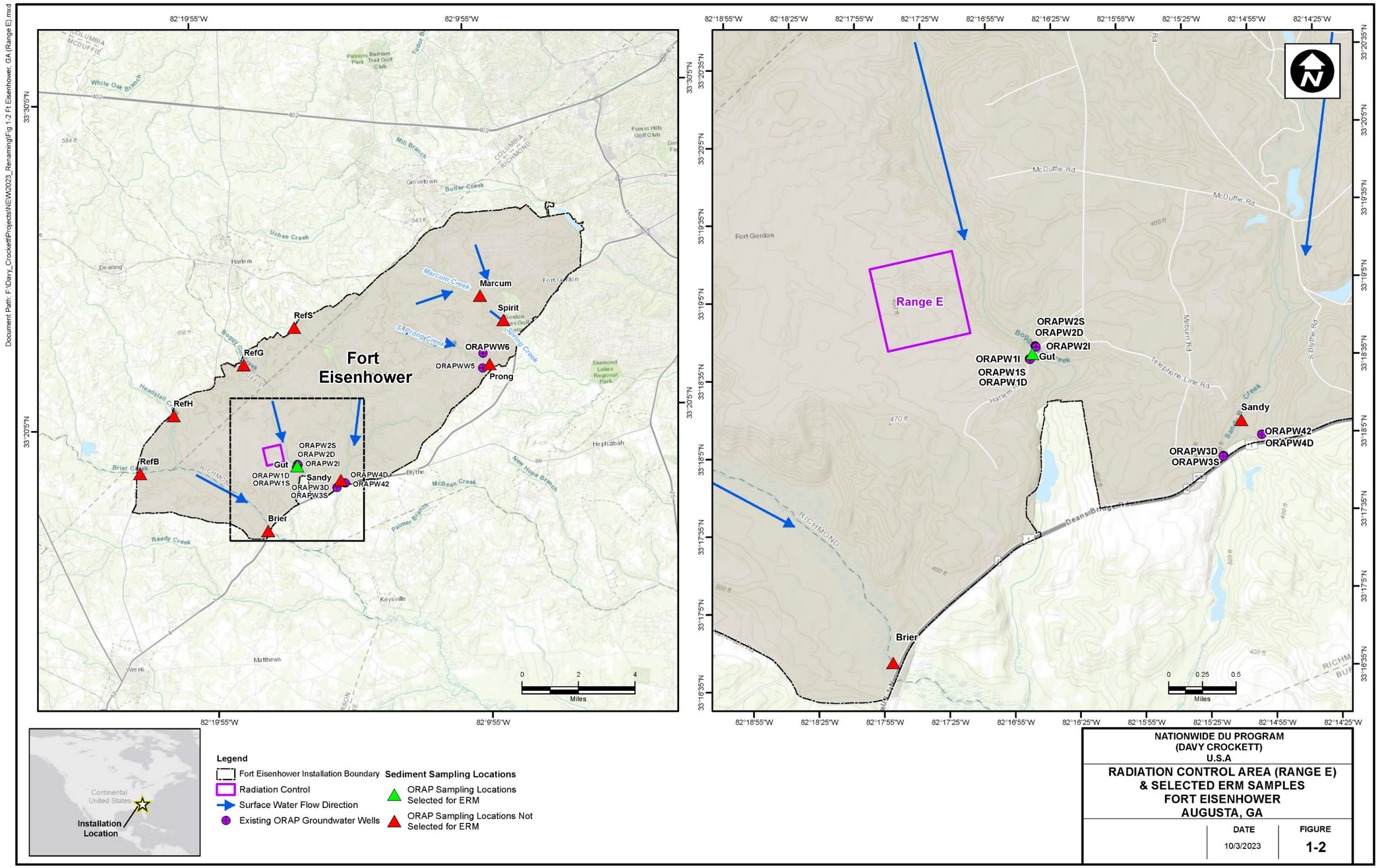

Figure 1-2. Radiation Control Area (Range E) and Selected ERM Samples

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1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCA at Fort Eisenhower are as follows:

- ***Surface Water Use***—No known use of surface water exists for consumption of drinking water downstream from Fort Eisenhower.
- ***Recreational Use***—Observations during the U.S. Army Operational Range Assessment Program (ORAP) Phase II sampling indicated that fishing occurred regularly in at least one of the creeks immediately below the installation boundary. Although human receptors are identified in the ORAP Phase I assessment as being exposed via the food chain from off-range recreational fishing, evidence suggests that the limited uptake and bioaccumulation of metals, explosives, and perchlorate in fish do not pose a risk to humans when consumed at the recreational level.
- ***Sensitive Environments***—The State of Georgia Department of Natural Resources defines significant groundwater recharge areas as environmentally sensitive land, and Fort Eisenhower sits on top of recharge areas for the Cretaceous aquifers. The majority of the creeks in the area are bordered by wetlands, which are considered sensitive environments of concern.
- ***Habitat***—The dry, upland habitats are characterized by sandy soil and are generally dominated by pine/scrub oak communities. Wetlands are present along a majority of the creeks, streams, and rivers on the installation.
- ***Ecological Receptors***—Some 28 state- and/or Federal-listed threatened and endangered plants and animals known to occur around Fort Eisenhower, including the red-cockaded woodpecker and gopher tortoise.
- ***Groundwater Use***—Fort Eisenhower is located in a recharge zone for the drinking water aquifers underneath and downgradient from the installation. Shallow groundwater recharges the deeper drinking water aquifers, which is a source of drinking water for remote areas of Fort Eisenhower and off-installation communities to the south and southeast. The installation wells inside Fort Eisenhower are in close proximity to active ranges. The off-installation communities of Blythe, Hephzibah, parts of Augusta-Richmond County, and Keysville are within 4 miles of the range boundary.

Potential human receptors include those within Fort Eisenhower and nearby communities who use potable water from wells. Ecological receptors include sensitive environments (e.g., wetlands, aquifers, and endangered species).

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCA at Fort Eisenhower are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of one sample from a location downstream from the RCA near the Fort Eisenhower installation boundary (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling location at Fort Eisenhower was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***Gut***—The selected sampling point is located on the Boggy Gut Creek, downstream from the RCA near the installation's southeastern boundary. The entire RCA is located within the Boggy Gut Creek watershed.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the Range E RCA based on surface water hydrology and the potential for DU contribution, and are located as follows:

- ***Brier***—The ORAP sampling point is located on Brier Creek, upstream of where Boggy Gut Creek enters Brier Creek. This sampling point is no longer relevant because the RCA is not within the portion of the Brier Creek watershed sampled at this location.
- ***Sandy Run, South Prong, Marcum Branch, and Spirit Creek***—These ORAP sampling points are located on the Sandy Run Creek, South Prong Creek, Marcum Branch, and Spirit Creek, respectively. The RCA is not located within the watersheds for any of these creeks. These sampling points are no longer relevant because the RCAs are not within their watersheds.
- ***RefB, RefH, RefG, RefS***—These ORAP sampling points are located on Brier Creek, Headstall Creek, Boggy Gut Creek, and Sandy Run Creek, respectively, where they enter the installation. These background/reference sampling locations are not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.

Surface water and sediment samples will be analyzed for total/isotopic uranium using the U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 based on alpha spectrometry. Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the

notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for Fort Gordon, Georgia, Annex 6 (ML16265A240) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, Gut, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6, in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a). The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Eisenhower are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b); Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (ML19115A040) (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2. Surface water and sediment samples collected during the ORAP Phase II assessment in 2006 were not analyzed for radiological parameters (USACHPPM 2008).

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
Gut	5/23/2017	ND
Gut	8/30/2017	ND
Gut	12/5/2017	ND
Gut	3/7/2018	ND
Gut	6/12/2018	ND
Gut	9/5/2018	ND
Gut	12/4/2018	ND
Gut	3/13/2019	ND
Gut	6/18/2019	ND
Gut	9/25/2019	ND
Gut	11/5/2019	ND
Gut	3/13/2020	ND
Gut	6/17/2020	ND
Gut	9/11/2020	ND
Gut	12/3/2020	0.64 ± 0.53
Gut	3/10/2021	NC
Gut	10/21/2021	NC
Gut	3/10/2022	NC
Gut	10/11/2022	NC

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
Gut	5/23/2017	1.1 ± 1
Gut	8/30/2017	1.1 ± 0.3
Gut	12/5/2017	0.95 ± 0.31
Gut	3/7/2018	0.74 ± 0.26
Gut	6/12/2018	1.2 ± 0.4
Gut	9/5/2018	0.83 ± 0.37
Gut	12/4/2018	1.0 ± 0.4
Gut	3/13/2019	1.2 ± 0.4
Gut	6/18/2019	0.81 ± 0.28
Gut	9/25/2019	0.73 ± 0.23
Gut	11/5/2019	1.1 ± 0.4
Gut	3/13/2020	0.94 ± 0.29
Gut	6/17/2020	0.87 ± 0.29
Gut	9/11/2020	ND
Gut	12/3/2020	1.2 ± 0.4
Gut	3/10/2021	NC
Gut	10/21/2021	1.3 ± 0.5
Gut	3/10/2022	0.95 ± 0.56
Gut	10/11/2022	0.89 ± 0.56

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level). ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at Fort Eisenhower.

2.2 GROUNDWATER

Fort Eisenhower is located within a well-defined groundwater recharge zone. Groundwater discharges directly to the surface water through springs and natural seepages. Any DU potentially present in the groundwater would likely have been detected through surface water and sediment sampling. For this reason and additional rationale included in the PAERMP (U.S. Army 2020a), groundwater sampling is not planned for Fort Eisenhower.

Groundwater samples collected during the ORAP Phase II assessment in 2006 were not analyzed for radiological parameters (USACHPPM 2008). The existing groundwater monitoring wells are shown in Figure 1-2.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who

will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Eisenhower does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020a).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedure (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Eisenhower will be coordinated with the Fort Eisenhower Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (30 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for the Fort Eisenhower RCA

Parameter		Default Value	Range E	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	2.95×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC Materials License (NRC 2016). = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	2.70×10^{-4}	
	U-238	N/A	0.04	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 10 to 150 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Groundwater flows southeast across RCA
Contaminated zone total porosity		0.4	0.39	RESRAD Manual Table E.8 (DOE 2001) for Coarse Sand
Contaminated zone hydraulic conductivity (m/y)		10	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	7.4	**www.usa.com for Augusta, GA**
Precipitation rate (annual rainfall) (m/y)		1.0	1.14	**www.usa.com for Augusta, GA**
Saturated Zone				
Saturated zone total porosity		0.4	0.39	RESRAD Manual Table E.8 (DOE 2001) for Coarse Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Saturated zone hydraulic conductivity (m/y)		100	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual Table E.8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Coarse Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand

*See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for the Fort Eisenhower RCA

RCA Layout Parameter	Range E			
Distance to nearest normally occupied area (m)	2,400			
Bearing of X axis (degrees)	225 (southeast)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	3500	3532
Leafy vegetables plot	500	531.25	3534	3566
Pasture, silage growing area	500	600	3716	3816
Grain fields	500	600	3566	3666
Dwelling site	500	531.25	3400	3432
Surface-water body	500	800	3816	4116
Atmospheric Transport Parameter				
Meteorological STAR file	GA_AUGUSTA.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	2400			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	2816			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	45			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for the RCA evaluated at Fort Eisenhower does not exceed 1.0×10^{-2} milliSievert/year (mSv/y) (1.0 [millirem per year] mrem/y) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Eisenhower Range E	4.6×10^{-3}	3.7×10^{-3}

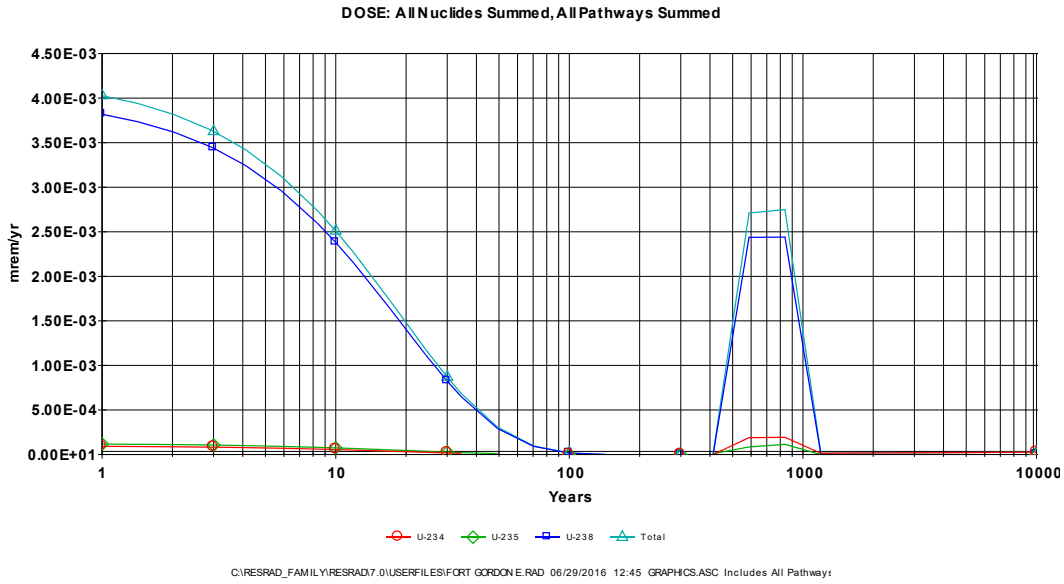
[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

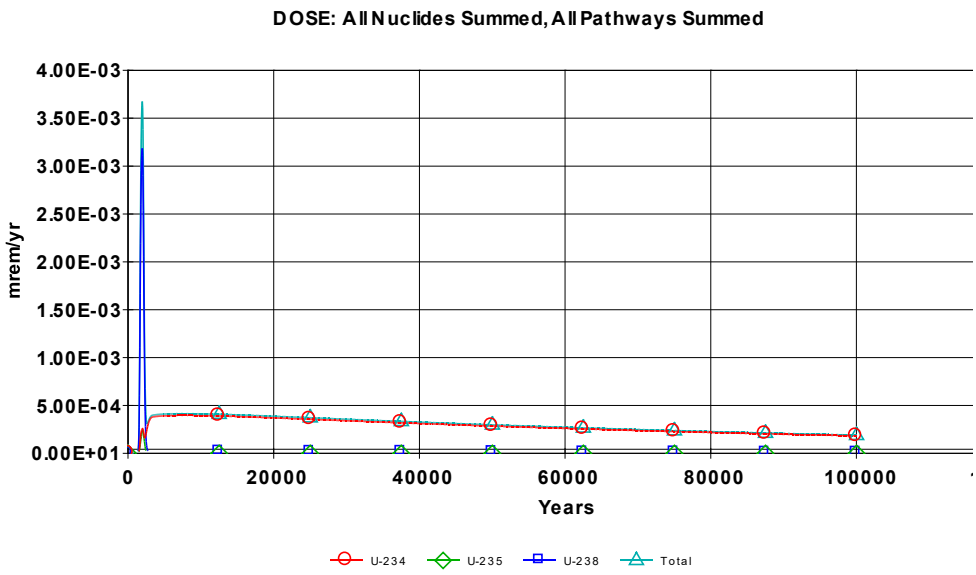
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Eisenhower Range E

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT CAVAZOS, TEXAS ANNEX 7

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IDQTF	Intergovernmental Data Quality Task Force
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
MCOC	Munitions Constituent of Concern
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to Fort Cavazos, Texas, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Hood, Texas, Annex 2 (ML21165A013) (U.S. Army 2020a) and documents the Installation name change from Fort Hood, Texas, to Fort Cavazos, Texas, on May 9, 2023.

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Cavazos. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream (**ERM-01** and **ERM-02**) from the Davy Crockett RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Cavazos is located in central Texas approximately 60 miles north of Austin and 50 miles southwest of Waco. The installation is bound on the north by the city of Gatesville, on the east by Belton Lake and the town of Temple, and on the south by the city of Killeen.

The territory of Camp Hood (current Fort Cavazos) was initially selected in 1941 for the preparation of soldiers in the use of tank destroyer combat during World War II. The Tank Destroyer Center relocated from Fort George G. Meade, Maryland, to the camp in 1942. By 1943, the initial range construction was complete and included 39 firing ranges and 2 cantonment areas (Main Cantonment area and North Fort Hood Cantonment), including 5,630 buildings. In 1944, the mission of the camp changed from tank destroyer to infantry training; subsequently, the camp became a permanent installation and was renamed Fort Hood. Various armored divisions have been assigned to Fort Hood over its 67-year history, and it is currently the largest active U.S. Army installation with the capability to house large quantities of assigned personnel and two divisions. In 2023, Fort Hood was renamed Fort Cavazos.

Currently, Fort Cavazos has a 198,257-acre operational footprint composed of 193 ranges, and a 20,245-acre non-operational area primarily composed of 3 cantonment areas and a recreation area. Fort Cavazos' primary mission is to provide housing and state-of-the-art training for units from the U.S. Army, U.S. Army National Guard, and U.S. Army Reserves to support mobilization and deployment of troops. Training activities conducted at Fort Cavazos include the use of weapons firing points; demolition ranges; firing ranges; and training and maneuver areas for mechanized maneuver and small unit exercises, combined arms training, and live-fire training (III Corps and Fort Hood 2006).

An Archives Search Report (ASR) (USACE 2008) confirmed the presence of one range where the Davy Crockett weapons system was used at Fort Cavazos. The Davy Crockett Range or radiation control area (RCA) consists of 245 acres (Figures 1-1 and 1-2). The nearest normally occupied areas to the Davy Crockett Range RCA are located approximately 3.4 miles south southwest of the RCA. Ro-delete MCOC in acronym list if no longer in.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968.

These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the Fort Cavazos; therefore, it is assumed that most, if not all, of the 770 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Cavazos is situated within the Lampasas Cut Plain, an eroded portion of the Comanche Plateau in east central Texas characterized by valleys, buttes, and plateaus. Generally, Fort Cavazos is characterized by moderately flat to gently rolling terrain, except in the central portion of the installation where topographic highs (plateaus) trend toward the Cowhouse Creek valley. Fort Cavazos lies within the Brazos River basin.

Geology beneath Fort Cavazos generally consists of consolidated sedimentary rocks from the Lower Cretaceous Comanche Series, which contains, from oldest to youngest, the Travis Peak, Glen Rose, and Paluxy Sand formations of the Trinity Group; the Walnut Clay, Comanche Peak Limestone, Edwards Limestone, and Kiamichi Clay formations of the Fredericksburg Group; and the Duck Creek Limestone, Fort Worth Limestone, and Denton Clay formations of the Washita Group.

Groundwater beneath Fort Cavazos is generally encountered at approximately 30 feet below ground surface (bgs) within the shallow alluvial aquifer. Recharge of the shallow aquifer occurs near the Leon

River; its associated tributaries; and through karst features, including caves, sinkholes, and springs formed in the Edwards limestone.

The shallow alluvial aquifer is separated from the deeper Trinity aquifer (primary potable water resource) by the intervening Walnut Clay Formation (approximately 200 feet thick). The presence of the confining unit precludes the migration of groundwater from the overlying Edwards Formation limestone into the deeper Trinity aquifer. Groundwater likely discharges to surface water prior to exiting the installation boundary.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors at Fort Cavazos are as follows:

- ***Surface Water Use***—A public surface water intake is located downstream from the RCA in Belton Lake (potable water for Fort Cavazos and the surrounding communities). It should be noted that even though Belton Lake is a potable water resource, consumers of lake water are not considered to be receptors because of recent non-detect sampling results from surface intake.
- ***Recreational Use***—Surface water bodies located downstream from on-range source areas, including Belton Lake and the Leon River and its tributaries, are used for recreational purposes (i.e., fishing).
- ***Sensitive Environments***—While no formal wetland delineation has been completed for the Fort Cavazos area, wetlands have the potential to surround the floodplain areas of the perennial water bodies both on- and off-installation, including Belton Lake and other perennial tributaries, near the perimeter of lakes and ponds, and in low-lying areas where groundwater intercepts the soil (III Corps and Fort Hood 2006).
- ***Habitat***—The habitats located on Fort Cavazos include short and tall grass prairies, and forest and shrub communities. The short grass prairies dominate the central portions of the installation near the impact areas and live-fire ranges and are composed of little bluestem, hairy grama, and sideoats grama grasses. The small clumps of tall grass prairie that are intermingled with the short grass prairie are composed of yellow Indiangrass and big bluestem grasses. Potential wetland habitats may be near saturated areas surrounding lakes, ponds, rivers, streams, and springs at Fort Cavazos. Plant species associated with potential wetlands inhabitants include broad-leaved cattail, black willow, duckweed, and sedges.
- ***Ecological Receptors***—There are eight Federal and/or state-listed threatened or endangered species known to occur at Fort Cavazos. Federal special species include one plant species (Texabama croton) and two fish (Guadalupe bass, smalleye shiner). Federally listed endangered species include three bird species (whooping crane, black-capped vireo, golden-cheeked warbler), while state-listed threatened species include one bird (Arctic peregrine falcon).
- ***Groundwater Use***—The primary source of potable water is surface water for Fort Cavazos and the surrounding communities, which is supplied from Belton Lake via Gatesville Water Treatment Facility and Water Control and Improvement District No. 1.

Potential receptors include off-range human (e.g., fisherman) and ecological receptors (e.g., wetlands).

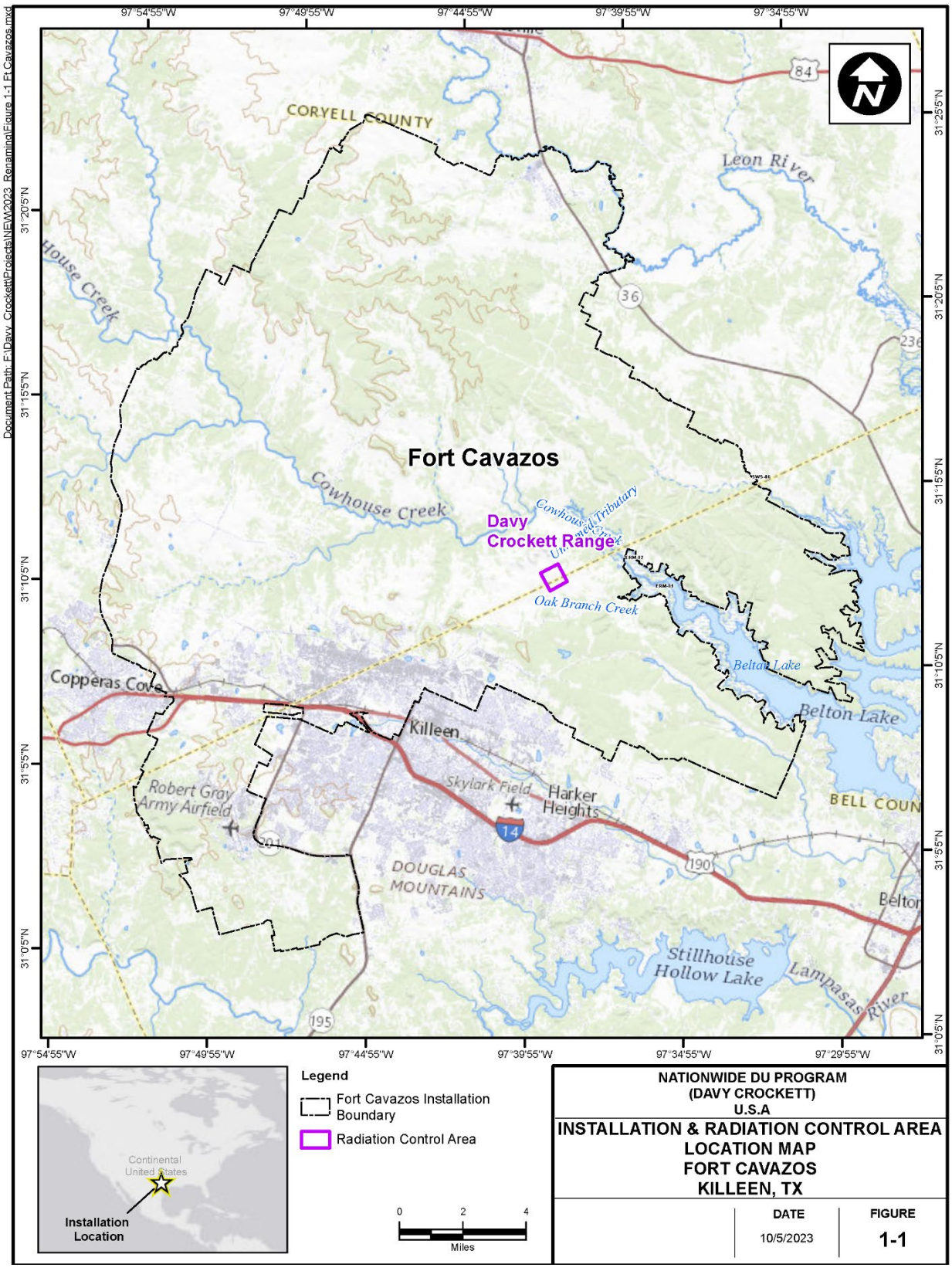

Figure 1-1. Installation and Radiation Control Area Location Map

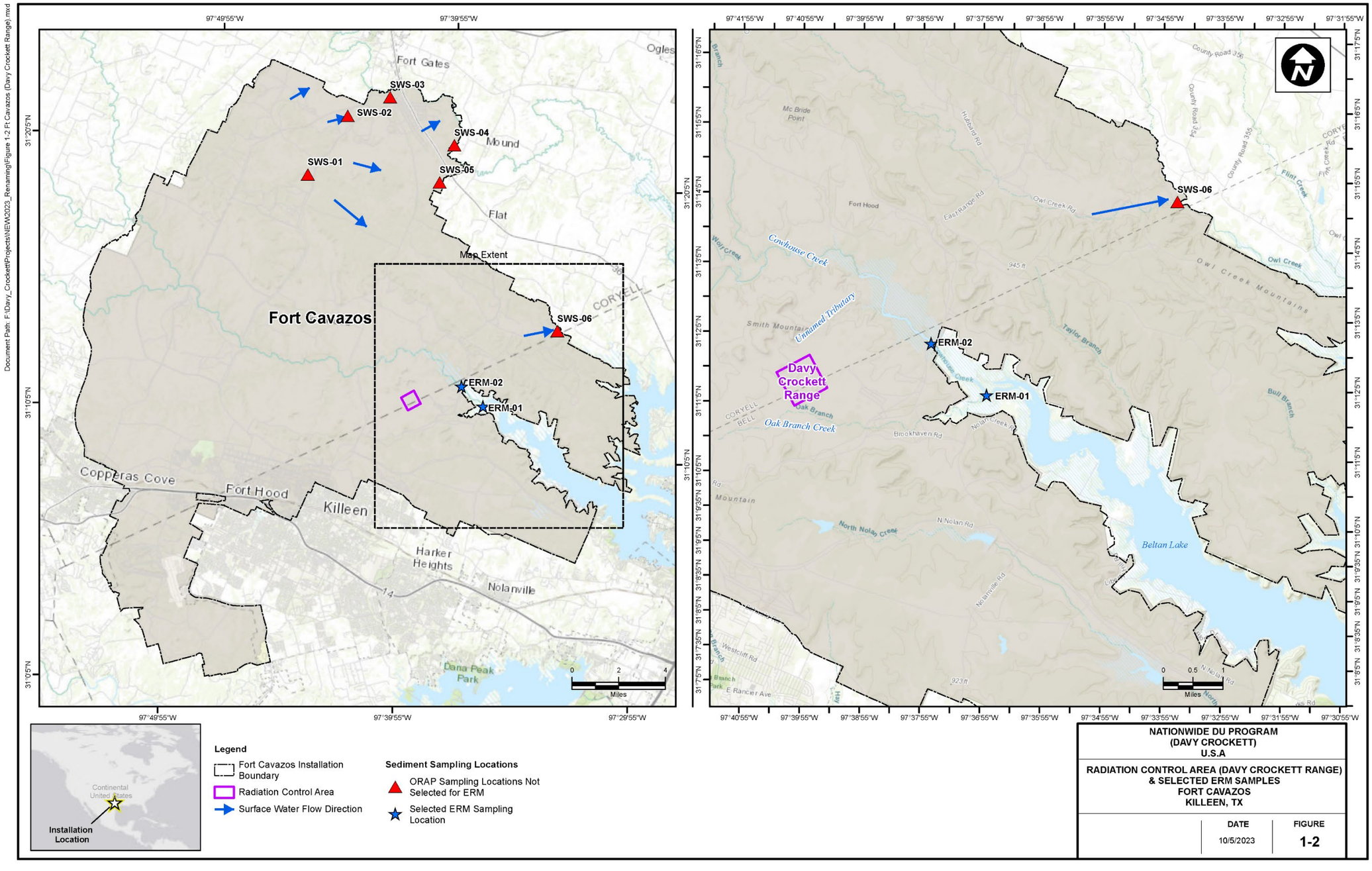

Figure 1-2. Radiation Control Area (Davy Crockett Range) and Selected ERM Samples

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Davy Crocket Range RCA at Fort Cavazos are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of samples from two locations downstream from the RCA at Fort Cavazos (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling locations at Fort Cavazos were selected based on the surface hydrology and potential for DU contribution and are located as follows:

- ***ERM-01***—The selected sampling point is located on the Oak Branch at the surface water exit point from the installation boundary. The Oak Branch appears to be an intermittent creek. Effort should be made to obtain samples during periods when surface water is present.
- ***ERM-02***—The selected sampling point is located on Cowhouse Creek at the surface water exit point from the installation boundary.

The first sample location, ERM-01, is on the Oak Branch, which runs south of the RCA and appears to be an intermittent creek that ultimately flows into Belton Lake. Water from the Oak Branch does not physically cross the RCA but is close enough to potentially contain surface water runoff from the RCA. The second sampling location, ERM-02, is on Cowhouse Creek, which receives water from an unnamed tributary that briefly crosses the northernmost section of the RCA. Cowhouse Creek ultimately flows into Belton Lake. The sample locations were selected downstream from Cowhouse Creek and the Oak Branch at the surface water exits points from the installation boundary. The Operational Range Assessment Program (ORAP) Phase II sample locations (i.e., SWS-01, SWS-02, SWS-03, SWS-04, SWS-05, and SWS-06) were not recommended for the environmental radiation monitoring (ERM) because of their lack of hydrologic connection to the RCA. In addition, surface water and sediment samples collected during the ORAP Phase II assessment in 2006 were not analyzed for radiological parameters (EA 2012).

Surface water and sediment samples will be analyzed for total/isotopic uranium using the U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for Fort Hood, Texas, Annex 7 (ML16265A241) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, ERM-01 and ERM-02, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6, in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a). The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Cavazos are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b); Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (ML19115A040) (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
ERM-01	6/7/2017	0.62 ± 0.66
ERM-02	6/7/2017	1.0 ± 0.8
ERM-01	8/16/2017	0.54 ± 0.39
ERM-02	8/16/2017	0.75 ± 0.46
ERM-01	12/5/2017	0.67 ± 0.35
ERM-02	12/5/2017	0.65 ± 0.36
ERM-01	3/27/2018	1.0 ± 0.4
ERM-02	3/27/2018	0.65 ± 0.31
ERM-01	6/11/2018	0.33 ± 0.15
ERM-02	6/11/2018	1.2 ± 0.9
ERM-01	9/4/2018	1.1 ± 0.8
ERM-02	9/4/2018	0.67 ± 0.44
ERM-01	12/18/2018	0.83 ± 0.35
ERM-02	12/18/2018	0.57 ± 0.21
ERM-01	2/26/2019	0.82 ± 0.22
ERM-02	2/26/2019	0.72 ± 0.19
ERM-01	6/4/2019	0.71 ± 0.35
ERM-02	6/4/2019	0.67 ± 0.29
ERM-01	9/16/2019	0.96 ± 0.49
ERM-02	9/16/2019	ND
ERM-01	11/19/2019	0.68 ± 0.4
ERM-02	11/19/2019	0.87 ± 0.38
ERM-01	2/25/2020	0.68 ± 0.4
ERM-02	2/25/2020	0.71 ± 0.38
ERM-01	6/9/2020	1.0 ± 0.5
ERM-02	6/9/2020	0.77 ± 0.35
ERM-01	9/17/2020	1.1 ± 0.4
ERM-02	9/17/2020	0.96 ± 0.36
ERM-01	11/17/2020	1.0 ± 0.6
ERM-02	11/17/2020	1.1 ± 0.5
ERM-01	5/27/2021	NC
ERM-02	5/27/2021	NC
ERM-01	9/15/2021	NC

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events (Continued)

Sample Location	Date	U-238/U-234 Ratio* (unitless)
ERM-02	9/15/2021	0.75 ± 0.3
ERM-01	5/18/2022	0.86 ± 0.61
ERM-02	5/18/2022	0.94 ± 0.64
ERM-01	8/24/2022	1.3 ± 0.94
ERM-02	8/24/2022	NC

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
ERM-01	6/7/2017	0.88 ± 0.34
ERM-02	6/7/2017	1.0 ± 0.4
ERM-01	8/16/2017	1.1 ± 0.4
ERM-02	8/16/2017	1.1 ± 0.4
ERM-01	12/5/2017	0.87 ± 0.31
ERM-02	12/5/2017	0.87 ± 0.29
ERM-01	3/27/2018	1.2 ± 0.4
ERM-02	3/27/2018	0.90 ± 0.28
ERM-01	6/11/2018	1.0 ± 0.3
ERM-02	6/11/2017	0.98 ± 0.3
ERM-01	9/4/2018	1.3 ± 0.4
ERM-02	9/4/2018	1.0 ± 0.3
ERM-01	12/18/2018	1.3 ± 0.4
ERM-02	12/18/2018	0.78 ± 0.28
ERM-01	2/26/2019	1.0 ± 0.3
ERM-02	2/26/2019	0.86 ± 0.3
ERM-01	6/4/2019	1.0 ± 0.3
ERM-02	6/4/2019	1.1 ± 0.4
ERM-01	9/16/2019	1.2 ± 0.6
ERM-02	9/16/2019	1.5 ± 0.9
ERM-01	11/19/2019	1.4 ± 0.5
ERM-02	11/19/2019	0.97 ± 0.47
ERM-01	2/25/2020	1.2 ± 0.4
ERM-02	2/25/2020	1.0 ± 0.3
ERM-01	6/9/2020	0.76 ± 0.34
ERM-02	6/9/2020	0.58 ± 0.29
ERM-01	9/17/2020	1.0 ± 0.5
ERM-02	9/17/2020	1.1 ± 0.4
ERM-01	11/17/2020	0.91 ± 0.32
ERM-02	11/17/2020	0.87 ± 0.36
ERM-01	5/27/2021	1.8 ± 0.8
ERM-02	5/27/2021	0.96 ± 0.4
ERM-01	9/15/2021	0.98 ± 0.3
ERM-02	9/15/2021	0.92 ± 0.3
ERM-01	5/18/2022	0.97 ± 0.46

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events (Continued)

Sample Location	Date	U-238/U-234 Ratio* (unitless)
ERM-02	5/18/2022	0.70 ± 0.30
ERM-01	8/24/2022	1.2 ± 0.53
ERM-02	8/24/2022	1.3 ± 0.69

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Cavazos.

2.2 GROUNDWATER

No groundwater samples were collected during the ORAP Phase II assessment. Presently, no groundwater monitoring wells are located at or near the RCA. Groundwater beneath Fort Cavazos is generally encountered at approximately 30 feet bgs within the shallow alluvial aquifer. Recharge of the shallow aquifer typically occurs near the Leon River; its associated tributaries; and through karst features, including caves, sinkholes, and springs formed in the Edwards limestone.

The shallow alluvial aquifer is separated from the deeper Trinity aquifer (primary potable water resource) by the intervening Walnut Clay Formation (approximately 200 feet thick). The presence of the confining unit precludes the migration of groundwater from the overlying Edwards Formation limestone into the deeper Trinity aquifer. Groundwater likely discharges to surface water prior to exiting the installation boundary. As such, groundwater was not investigated during the ORAP Phase II assessment. DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020a), groundwater sampling is not planned for Fort Cavazos.

2.3 SOIL

If an area of soil greater than 25 m^2 eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Cavazos does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020a).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sample in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Cavazos will be coordinated with the Fort Cavazos Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is low

and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (770 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for the Fort Cavazos RCA

Parameter		Default Value	Davy Crockett Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	7.58×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC Materials License (NRC 2016). = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	6.93×10^{-3}	
	U-238	N/A	1.15	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC Radioactive Materials License SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 30 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Groundwater flows across RCA
Contaminated zone total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt (Soil described as 50/50 mixture of clay loam and silty clay).
Contaminated zone hydraulic conductivity (m/y)		10	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty clay loam.
Contaminated zone b parameter		5.3	7.75	RESRAD Manual Table E.2 (DOE 2001) for Silty clay loam.
Average annual wind speed (m/s)		2.0	7.4	www.usa.com
Precipitation rate (annual rainfall) (m/y)		1.0	0.83	www.usa.com
Saturated Zone				
Saturated zone total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty clay loam
Saturated zone b parameter		5.3	7.75	RESRAD Manual (DOE 2001) Table E.2 for Silty clay loam
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	7.75	RESRAD Manual Table E.2 (DOE 2001) for Silty clay loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty clay loam

*See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for the Fort Cavazos RCA

RCA Layout Parameter	Davy Crockett Range			
Distance to nearest normally occupied area (m)	5,400			
Bearing of X axis (degrees)	315 (southwest)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	6500	6532
Leafy vegetables plot	500	531.25	6534	6566
Pasture, silage growing area	500	600	6716	6816
Grain fields	500	600	6566	6666
Dwelling site	500	531.25	6400	6432
Surface-water body	500	800	6816	7116
Atmospheric Transport Parameter				
Meteorological STAR file	TX_WACO.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	5400			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	5816			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	135			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for the RCA evaluated at Fort Cavazos does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Cavazos Davy Crockett Range	0.13	3.8×10^{-4}

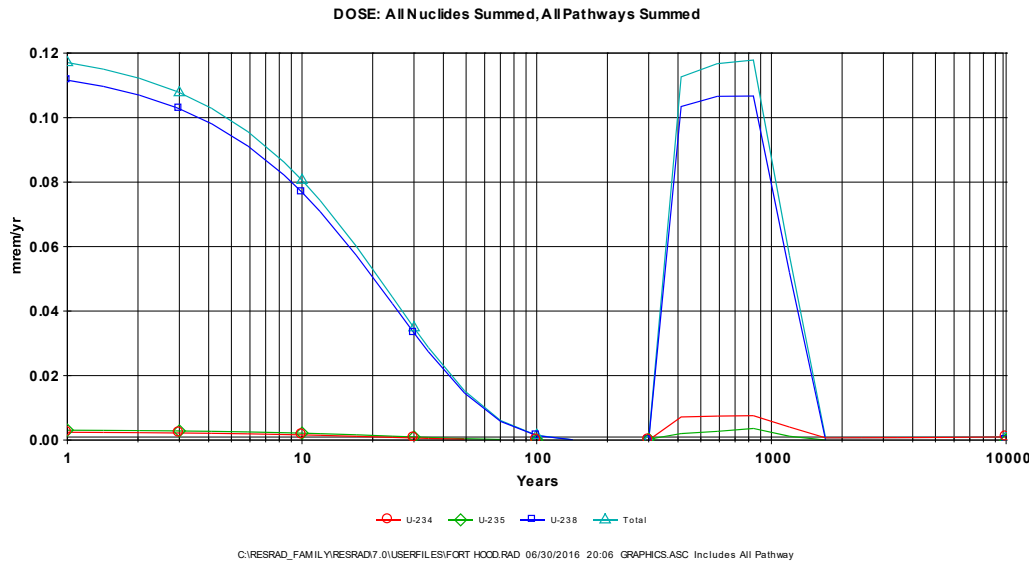
[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

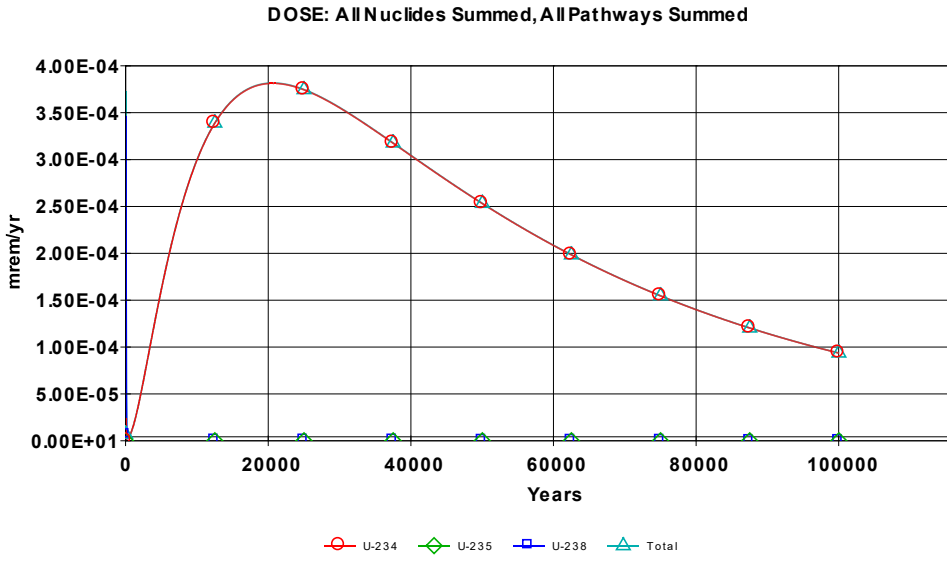
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Cavazos Davy Crockett Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT HUNTER LIGGETT, CALIFORNIA ANNEX 8

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mSr/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
USARC	U.S. Army Reserve Command
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Hunter Liggett, California, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Hunter Liggett, California, Annex 7 (ML16265A242) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Hunter Liggett. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream (**ERM-01** and **ERM-02**) from the RCAs, as shown in Figure 1-2, based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Fort Hunter Liggett is located approximately 3 miles from the Pacific Ocean in the central coastal region of California, 150 miles south of San Francisco and 250 miles north of Los Angeles (Figure 1-1). King City and Paso Robles are 23 miles northeast and 45 miles southeast, respectively. The installation encompasses 164,637 acres and is bound on the north by the Ventana Wilderness Area, on the east by the Salinas River Valley, on the south by the Monterey-San Luis Obispo county line, and on the west by approximately 55 miles of the Los Padres National Forest. Fort Hunter Liggett is the largest U.S. Army Reserve Command (USARC) installation in the United States.

Purchased from the estate of William Randolph Hearst and surrounding private landowners in 1940, Fort Hunter Liggett (originally designated Hunter Liggett Military Reservation in 1941) was established to train soldiers for combat in World War II. The initial property was 266,950 acres, of which 107,895 acres were acquired by transfer and 153,880 acres were obtained by fee. The area consisted mostly of local ranch land. Between 1946 and 1987, 91,000 acres were transferred to the National Park Service and U.S. Navy.

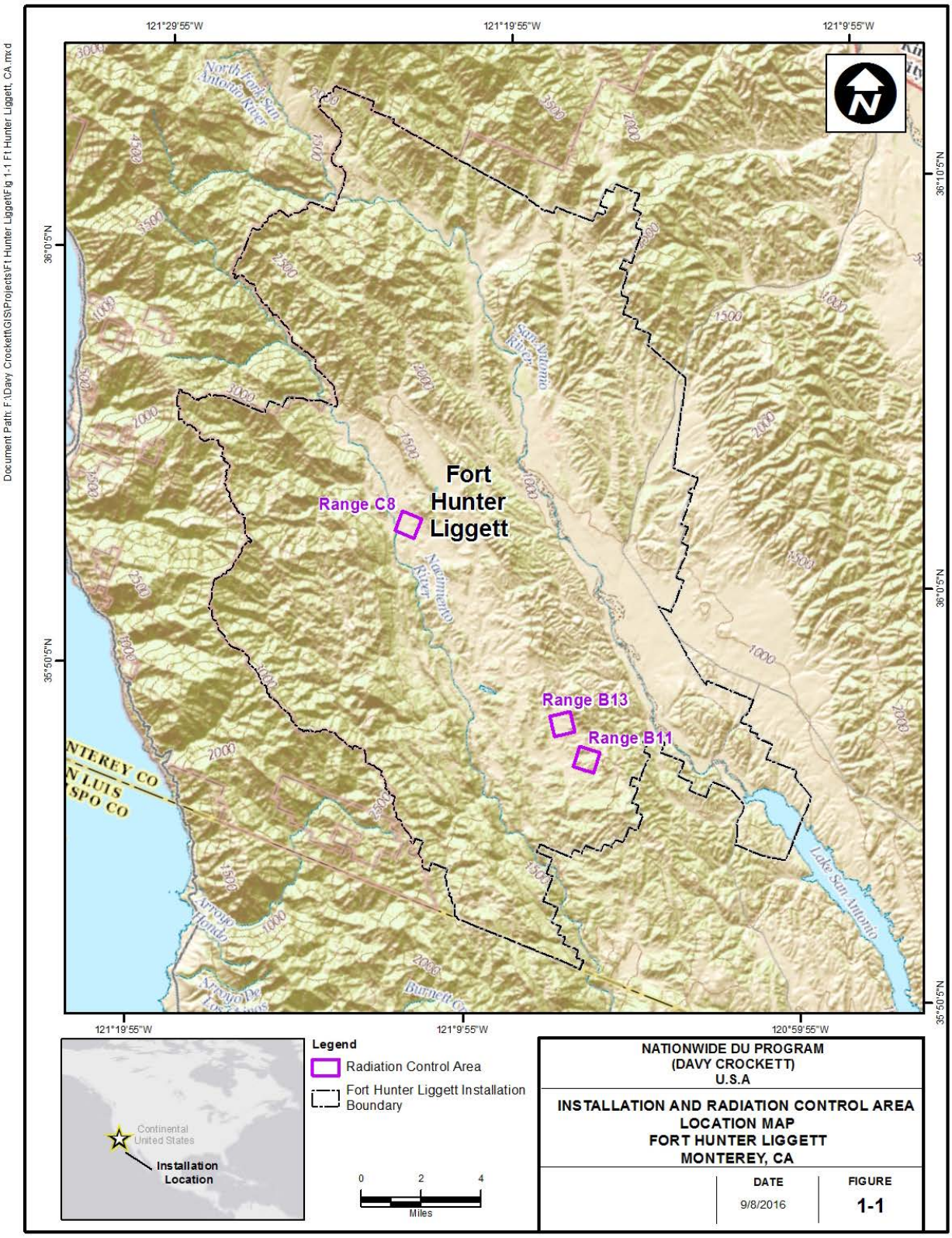

Figure 1-1. Installation and Radiation Control Area Location Map

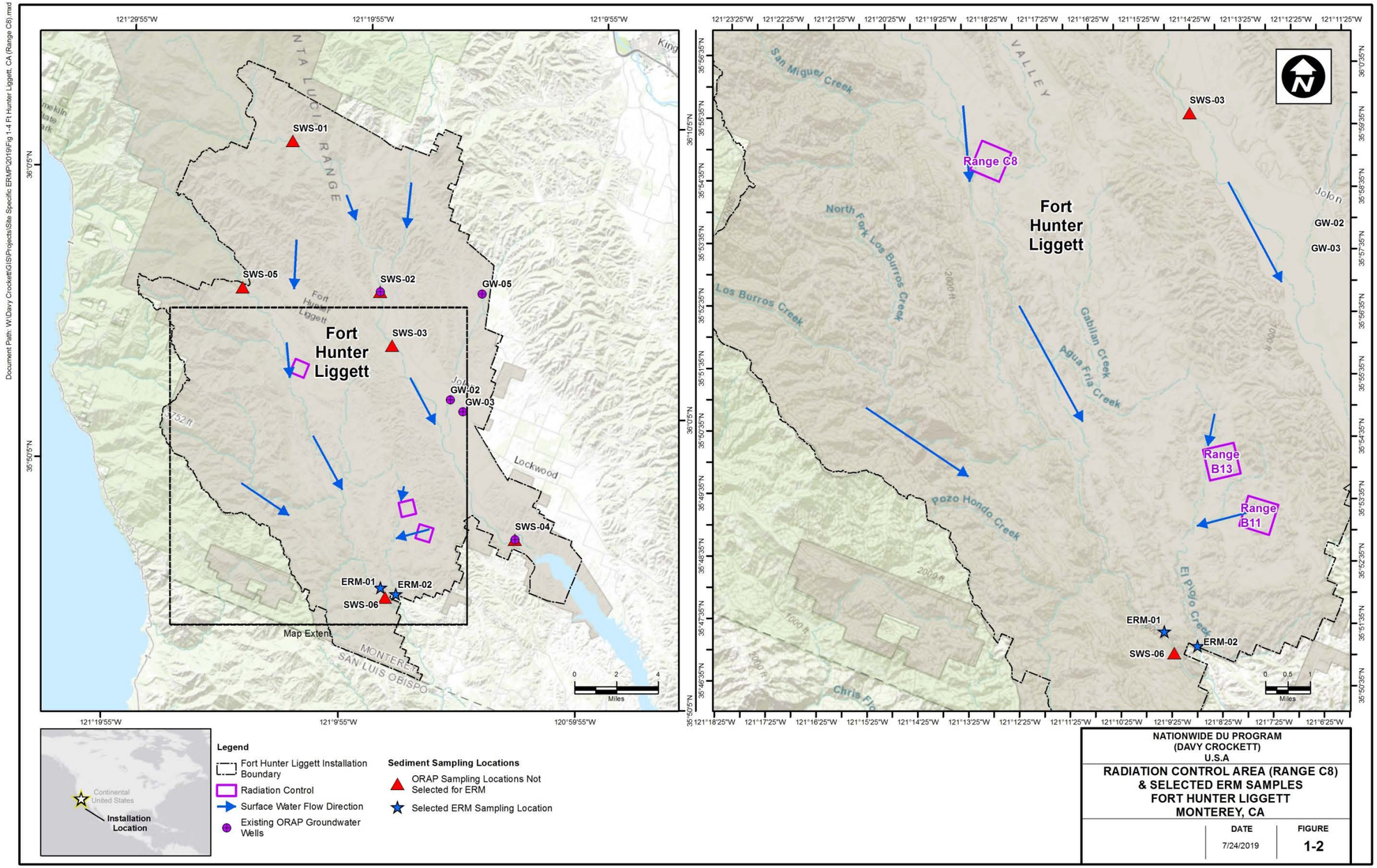

Figure 1-2. Radiation Control Areas (Range C8) and Selected ERM Samples

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Until 1952, Fort Hunter Liggett was under the administrative authority of Camp Roberts, located approximately 17 miles to the southeast. In 1953, the installation was transferred to the command of Fort Ord, California. While a sub-installation to Fort Ord, the installation was used by the Combat Development Experimentation Command as a proving ground for new and emerging defense technologies. In November 1993, command authority was transferred to USARC and Fort Hunter Liggett became a sub-installation of Fort McCoy, Wisconsin.

Currently, Fort Hunter Liggett provides "real world" training opportunities for active and reserve components of the Armed Forces. The mission of Fort Hunter Liggett focuses on maintaining and allocating training areas, airspace, facilities, and ranges in support of the U.S. Army's reserve and active components' field maneuvers, live-fire exercises, testing, and institutional training (EA 2008).

The installation utilizes 72 operational ranges, totaling approximately 154,849 acres. These ranges include a multi-purpose range complex; 6 observation points; 6 live-fire small arms ranges; 3 practice and high-explosive grenade ranges; 3 runways and heliports; 30 training areas (including light, heavy, and amphibious maneuver areas); a tank range; and a single heavy demolition range. Fort Hunter Liggett also utilizes 95,000 acres in the adjoining Los Padres National Forest for special operations training. The installation's total acreage also contains an estimated 9,305 non-operational acres (i.e., Cantonment Area, Ammunition Supply Point, and off limits protected areas).

An Archives Search Report (ASR) (USACE 2009) confirmed the presence of three ranges where the Davy Crockett weapons systems were used at Fort Hunter Liggett. Ranges B11, B13, and C8 or radiation control areas (RCAs) consist of 247 acres each (Figure 1-2). The nearest normally occupied areas to Ranges B11, B13, and C8 are 5.4, 5.8, and 4.5 miles, respectively.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Ranges B11, B13, or C8 on Fort Hunter Liggett; therefore, it is assumed that most, if not all, of the 30 kilograms (kg) of DU from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Fort Hunter Liggett is located within the northwest-trending Coast Ranges geological province and is situated between the Santa Lucia Mountain Range (to the southwest) and the Gabilan Range (to the northeast). The installation lies within the Santa Lucia Mountains' rain shadow. The average annual precipitation for the San Antonio River Valley is approximately 19 inches, with the majority falling between December and March. Winter rains typically begin in November or December, conclude in April or May, and are followed by a 6- to 7-month dry season (EA 2008). The annual evapotranspiration rate for the Fort Hunter Liggett region ranges from 50 to 58 inches per year.

There are two major rivers located on Fort Hunter Liggett: the San Antonio River and the Nacimiento River. Headwaters for both the San Antonio and Nacimiento Rivers are located northwest of the installation boundary in the Santa Lucia Range. Much of the Nacimiento River is dry during the summer months, though isolated pools can remain throughout the year. With the exception of its upper reaches, which are spring-fed, the San Antonio River is also primarily intermittent. The numerous tributaries that feed the two major rivers are considered intermittent; however, during the wet season, the streams are spring-fed. Off-installation, both rivers are dammed approximately 15 to 20 miles downstream to create reservoirs. The Nacimiento Reservoir is located several miles south of Fort Hunter Liggett, while the northern 2.5 miles of the San Antonio Reservoir is contained within the operational range area of the installation. Both reservoirs drain to the Salinas River 11 miles to the east of the installation; the Salinas River flows northwesterly and eventually drains into Monterey Bay approximately 90 miles away.

The majority of groundwater at Fort Hunter Liggett is contained within the Jolon-Lockwood groundwater basin and the Mission-San Antonio aquifer. The Jolon-Lockwood groundwater basin is recharged by the San Antonio River when it is flowing and from precipitation/runoff along the basin margins. Groundwater flow is parallel to the river and flows south toward the San Antonio Reservoir. Depth to groundwater generally ranges from 10 to 150 feet below ground surface (bgs); however, it varies seasonally with the availability of recharge from the San Antonio River. Well depths range from 30 feet bgs for domestic use to 1,000 feet bgs for municipal use. The Mission-San Antonio aquifer is a shallow, unconfined aquifer found in the unconsolidated alluvial deposits associated with the San Antonio River. Recharge to the Mission-San Antonio aquifer is from the San Antonio River, and groundwater is believed to follow fractures and faults southeastward and parallel to the San Antonio River. The Mission-San Antonio aquifer and the Jolon-Lockwood groundwater basin are separated by the Jolon fault, which may limit the hydraulic connectivity of the two aquifers.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for Ranges B11, B13, and C8 at Fort Hunter Liggett are as follows:

- ***Surface Water Use***—Surface water is not used as a potable water source at Fort Hunter Liggett.
- ***Recreational Use***—Both the San Antonio Reservoir and the Nacimiento Reservoir are designated as fishing and recreational areas. Water for these reservoirs is supplied by the San Antonio River and the Nacimiento Reservoir, which drain Fort Hunter Liggett.
- ***Sensitive Environments***—There is a Sensitive Resource Protection Area located within the Cantonment Area at Fort Hunter Liggett, which is protected from military and ground-disturbing activities..
- ***Habitat***—Sandy soil habitat for the Arroyo Toad and habitat for the San Joaquin Kit Fox are present in the Cantonment Area.
- ***Ecological Receptors***—Federally and state-listed threatened and endangered species and habitat, including the purple amole, as well as a Sensitive Resource Protection Area, are located within the cantonment area. Although vernal pools are present throughout the Cantonment Area and contain vernal pool fairy shrimp, the pools are not connected to the surface water system or groundwater and are, therefore, not affected by drainage from the site ranges.
- ***Groundwater Use***—Potential human receptors that may be affected by groundwater include users of groundwater wells on Fort Hunter Liggett that supply potable water to the Cantonment Area and private in-holdings, as well as individual residences within the non-operational area. However, all of the groundwater production wells are located in groundwater basins situated

in the San Antonio River watershed, but the San Antonio River watershed, which is where the RCAs are located, is separated from the Nacimiento River watershed by Bald Mountain.

Potential human receptors that may be affected by groundwater include users of groundwater wells on Fort Hunter Liggett that supply potable water to the Cantonment Area and private in-holdings, as well as individual residences within the non-operational area. Potential surface water receptors include state protected or threatened and/or federally endangered birds, mammals, and amphibians; sensitive habitats; and off-range recreational users of the San Antonio and Nacimiento reservoirs.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCAs or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for Ranges B11, B13, and C8 in Fort Hunter Liggett are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of samples from two locations downstream from the RCAs (Figure 1-2) at Fort Hunter Liggett where surface water flow is intermittent. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling locations at Fort Hunter Liggett were selected based on surface water hydrology and potential for DU contribution and are located as follows:

- ***ERM-01***—The selected sampling point is located on the Nacimiento River before surface water exits the installation boundary.
- ***ERM-02***—The selected sampling point is located on located on El Piojo Creek at the installation boundary.

The Operational Range Assessment Program (ORAP) Phase II assessment sample location, SWS-06, was the recommended environmental radiation monitoring (ERM) sample location in the Site-Specific ERMP for Fort Hunter Liggett, California, Annex 8 (ML16265A242) (U.S. Army 2016). The ORAP sample location, SWS-06, is located on the Nacimeiento River before surface water exits the installation boundary; however, SWS-06 was determined to be inaccessible due to limited roadways and steep terrain during the summer 2017 ERM sampling event. Prior to the fall 2017 ERM sampling event, the surface water hydrology and potential for DU contribution from the RCAs was evaluated and ERM-01 and ERM-02 were selected as the ERM sampling locations. In 2006, surface water and sediment samples were collected from the ORAP sampling location, SWS-06, along with additional sample locations during the ORAP Phase II assessment in 2011; however, the samples were not analyzed for radiological parameters (USACHPPM 2008).

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for Fort Hunter Liggett, California, Annex 8 (ML16265A242) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, ERM-01 and ERM-02, in 2017 and 2018. During the summer 2017 quarterly sampling event, the planned location for SWS-06 was inaccessible. The surface water and sediment samples were collected from an alternate point as close as possible to the original location that could be reached. The concentrations of total and isotopic uranium in sediment from the ERM sampling events at Fort Hunter Liggett are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-06	5/25/2017	0.88 +/- 0.29
ERM-01	9/21/2017	ND
ERM-02	9/21/2017	--- +/- ---
ERM-01	11/20/2017	--- +/- ---
ERM-02	11/20/2017	--- +/- ---
ERM-01	3/6/2018	ND
ERM-02	3/6/2018	0.82 +/- 0.21
ERM-01	6/7/2018	ND
ERM-02	6/7/2018	--- +/- ---
ERM-01	9/4/2018	--- +/- ---
ERM-02	9/4/2018	--- +/- ---
ERM-01	11/20/2018	--- +/- ---
ERM-02	11/20/2018	--- +/- ---

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
--- +/--- – Indicates surface water sample was not collected because water was not present during sampling.
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-06	5/25/2017	0.97 +/- 0.31
ERM-01	9/21/2017	0.85 +/- 0.41
ERM-02	9/21/2017	1.2 +/- 0.5
ERM-01	11/20/2017	1.1 +/- 0.4
ERM-02	11/20/2017	0.90 +/- 0.29
ERM-01	3/6/2018	0.98 +/- 0.32
ERM-02	3/6/2018	0.96 +/- 0.31
ERM-01	6/7/2018	0.86 +/- 0.24
ERM-02	6/7/2018	0.89 +/- 0.28
ERM-01	9/4/2018	1.2 +/- 0.4
ERM-02	9/4/2018	0.79 +/- 0.2
ERM-01	11/20/2018	0.80 +/- 0.28
ERM-02	11/20/2018	1.4 +/- 0.6

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at Fort Hunter Liggett.

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment groundwater sampling in October 2010 were not analyzed for radiological parameters (U.S. Army 2014). Presently, no groundwater monitoring wells are located at or near the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Hunter Liggett.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of environmental radiation samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, RCAs at Fort Hunter Liggett do not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Hunter Liggett will be coordinated with the Fort Hunter Liggett Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to establish the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (30 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Hunter Liggett RCAs

Parameter		Default Value	Range C8	Range B11	Range B13	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12			Conservative dose coefficients for site contaminants
Contaminated Zone						
Soil concentrations (pCi/g)	U-234	N/A	2.95×10^{-3}	2.95×10^{-3}	2.95×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	2.70×10^{-4}	2.70×10^{-4}	2.70×10^{-4}	
	U-238	N/A	0.04	0.04	0.04	
Area of contaminated zone (m^2)		10,000	1,000,000	1,000,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	0	Depth to groundwater is generally 10 to 150 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	1,000	Groundwater flows southeast across RCAs
Contaminated zone total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Contaminated zone hydraulic conductivity (m/y)		10	219	227	32.6	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Contaminated zone b parameter		5.3	5.39	5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Average annual wind speed (m/s)		2.0	7.4	7.4	7.4	www.usa.com
Precipitation rate (annual rainfall) (m/y)		1.0	0.54	0.54	0.54	www.usa.com
Saturated Zone						
Saturated zone total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt
Saturated zone effective porosity		0.2	0.20	0.20	0.20	RESRAD Manual Table E.8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	219	227	32.6	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Saturated zone b parameter		5.3	5.39	5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Unsaturated Zone						
Unsaturated zone 1, total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt
Unsaturated zone 1, effective porosity		0.2	0.20	0.20	0.20	RESRAD Manual Table E.8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	5.39	5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)
Unsaturated zone 1, hydraulic conductivity (m/y)		10	219	227	32.6	RESRAD Manual Table E.2 (DOE 2001) (Silty Loam for Range B11, Silty Clay for Range B13, Loam for Range C8)

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Hunter Liggett RCAs

RCA Layout Parameter	Range C8				Range B11				Range B13			
Distance to nearest normally occupied area (m)	4,000				7,000				7,000			
Bearing of X axis (degrees)	180 (east)				90 (north)				90 (north)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	5100	5132	500	531.25	8100	8132	500	531.25	8100	8132
Leafy vegetables plot	500	531.25	5134	5166	500	531.25	8134	8166	500	531.25	8134	8166
Pasture, silage growing area	500	600	5316	5416	500	600	8316	8416	500	600	8316	8416
Grain fields	500	600	5166	5266	500	600	8166	8266	500	600	8166	8266
Dwelling site	500	531.25	5000	5032	500	531.25	8000	8032	500	531.25	8000	8032
Surface-water body	500	800	5416	5716	500	800	8416	8716	500	800	8416	8716
Atmospheric Transport Parameter												
Meteorological STAR file	CA_SANTA_MARIA.str				CA_SANTA_MARIA.str				CA_SANTA_MARIA.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow) (m)	4000				7000				7000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	4416				7416				7416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	0				270				270			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Hunter Liggett does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Hunter Liggett Range C8	4.7×10^{-3}	1.9×10^{-3}
Fort Hunter Liggett Range B11	4.7×10^{-3}	2.2×10^{-3}
Fort Hunter Liggett Range B13	4.7×10^{-3}	1.9×10^{-5}

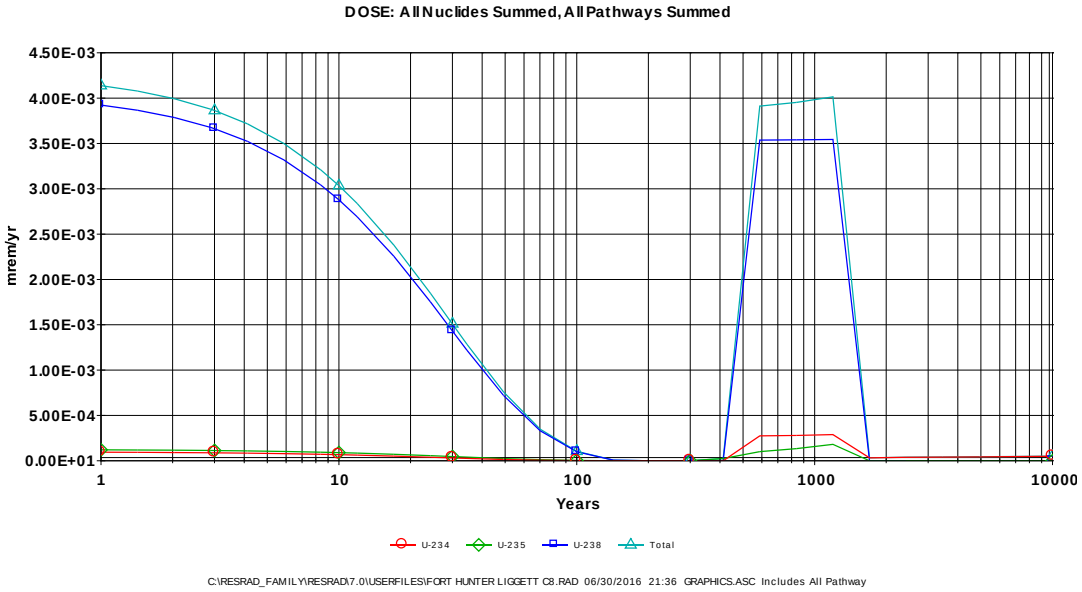
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

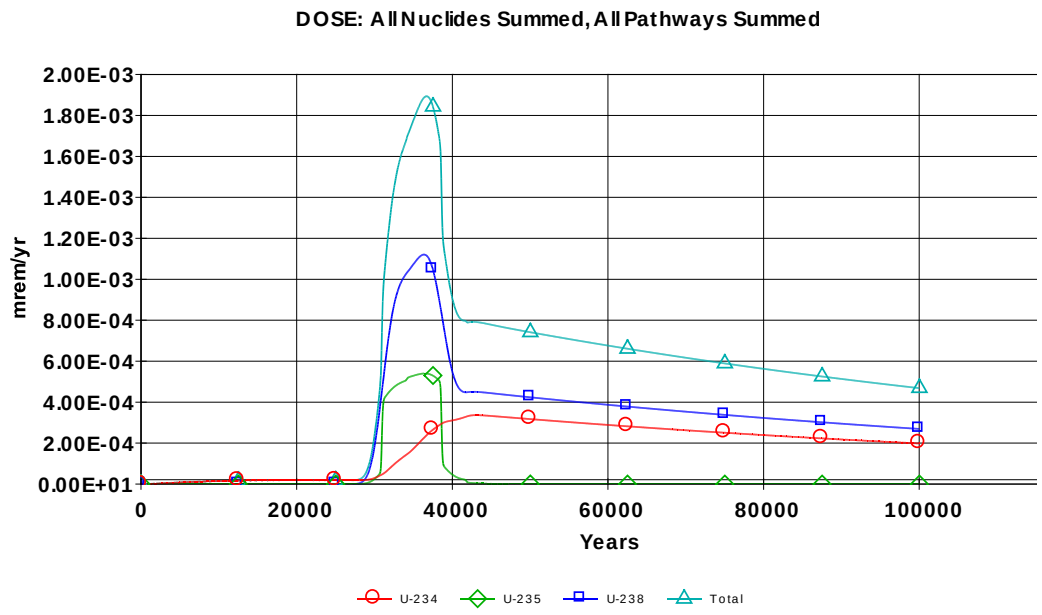
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Hunter Liggett Range C8

RCA Onsite (RESRAD)

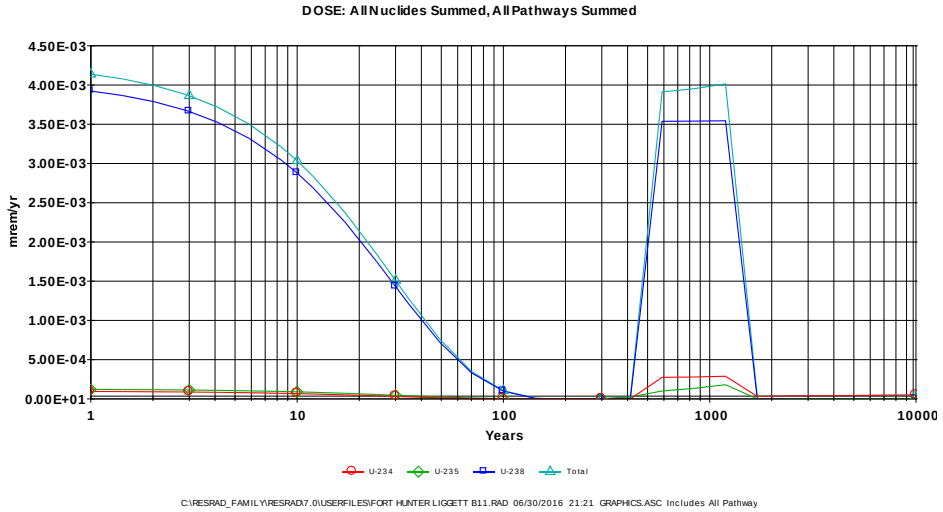


RCA Offsite (RESRAD-OFFSITE)

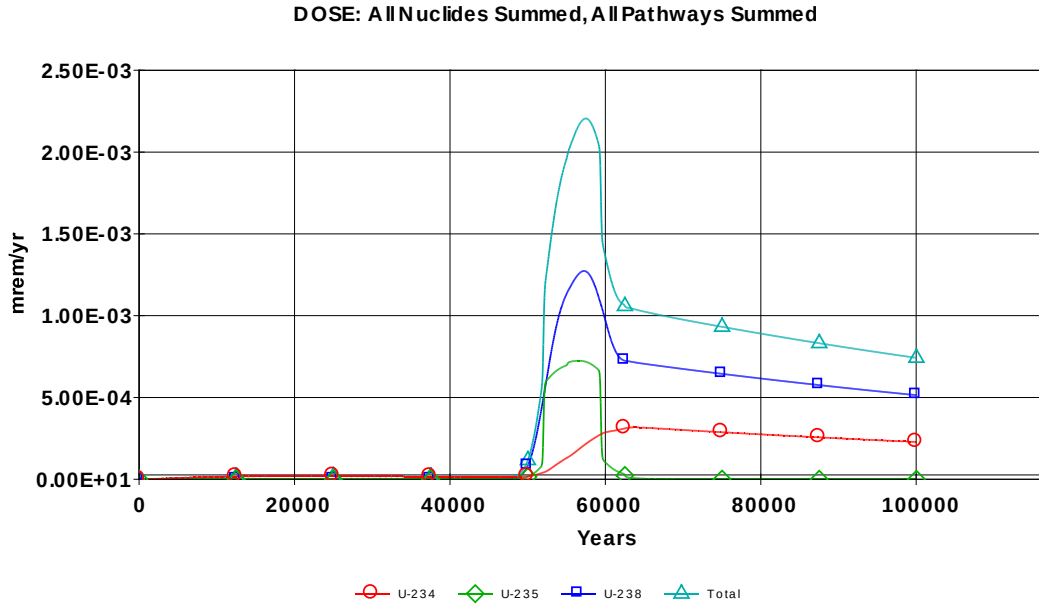


Fort Hunter Liggett Range B11

RCA Onsite (RESRAD)

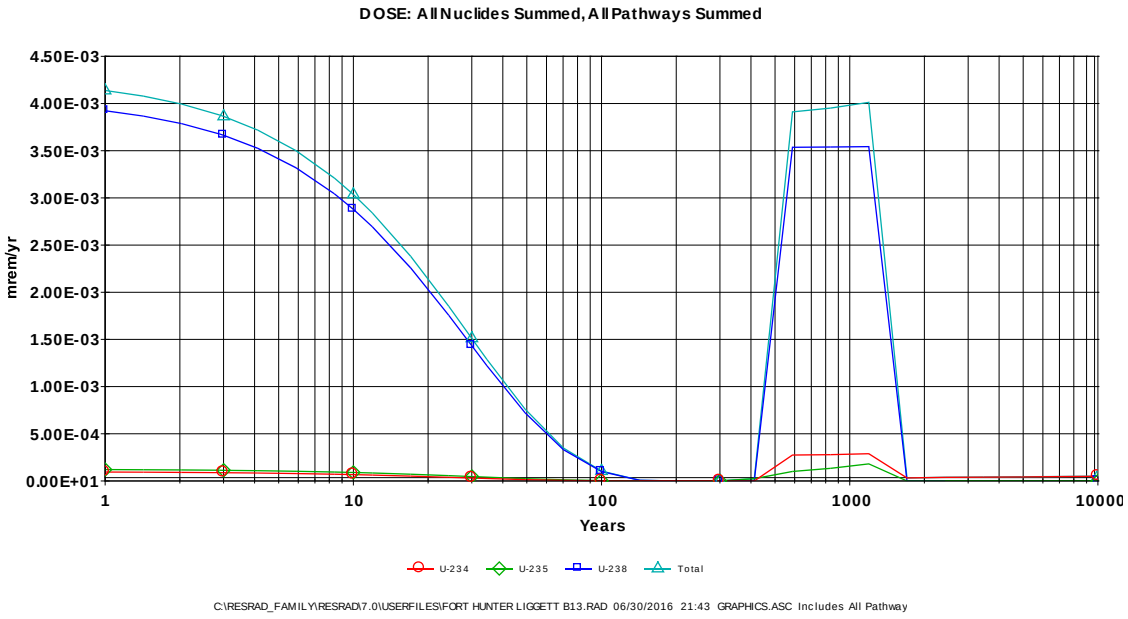


RCA Offsite (RESRAD-OFFSITE)

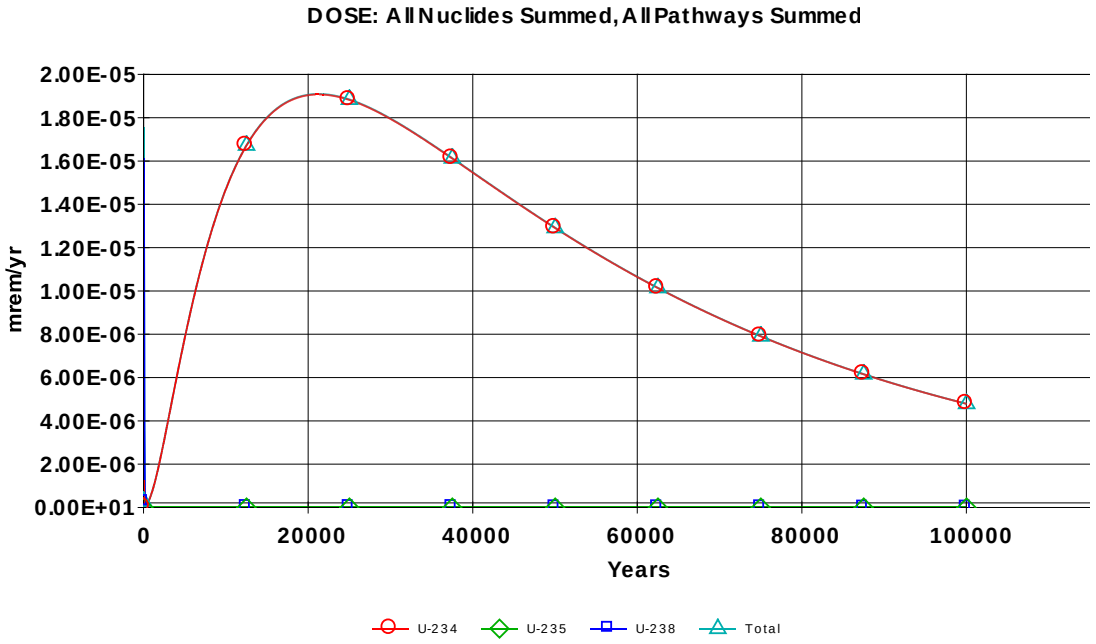


Fort Hunter Liggett Range B13

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\ \text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\ \text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\ \text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT JACKSON, SOUTH CAROLINA ANNEX 9

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
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ACRONYMS AND ABBREVIATIONS

µg/L	Micrograms per Liter
ARID-GEO	Army Range Inventory Database-Geodatabase
ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
MCL	Maximum Contaminant Level
mrem/y	Millirem per Year
msl	Mean Sea Level
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SCARNG	South Carolina Army National Guard
SCDNR	South Carolina Department of Natural Resources
SDWA	Safe Drinking Water Act
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Jackson, South Carolina, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Jackson, South Carolina, Annex 9 (ML16265A243) (U.S. Army 2016).

1.1 PURPOSE

The NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at the Fort Jackson. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream **(CC-3**) from the Range 62 RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Jackson, South Carolina constitutes a 51,961-acre installation located in Richland County, South Carolina (Figure 1-1). The entire installation is operational and includes 166 ranges.

The primary mission of this fort and associated areas is to train initial entry recruits for duty as soldiers for U.S. Army units. To support this mission, Fort Jackson currently houses U.S. Army training brigades and serves as a reception station that processes newly inducted and prior service personnel forwarded to the installation from recruiting and induction stations.

The Army Range Inventory Database-Geodatabase (ARID-GEO) (2006) includes 104 operational range areas at Fort Jackson encompassing a total of 29,475 acres and 62 ranges at the McCrady Training Center encompassing a total 15,267 acres. These operational areas support a variety of range uses including, live-fire weapons training, heavy and light maneuver exercises, Dudded and Non-Dudded Impact Areas, and specialty training such as night-infiltration and military operations in urban terrain. Many of these ranges currently receive heavy usage by soldiers undergoing initial military training.

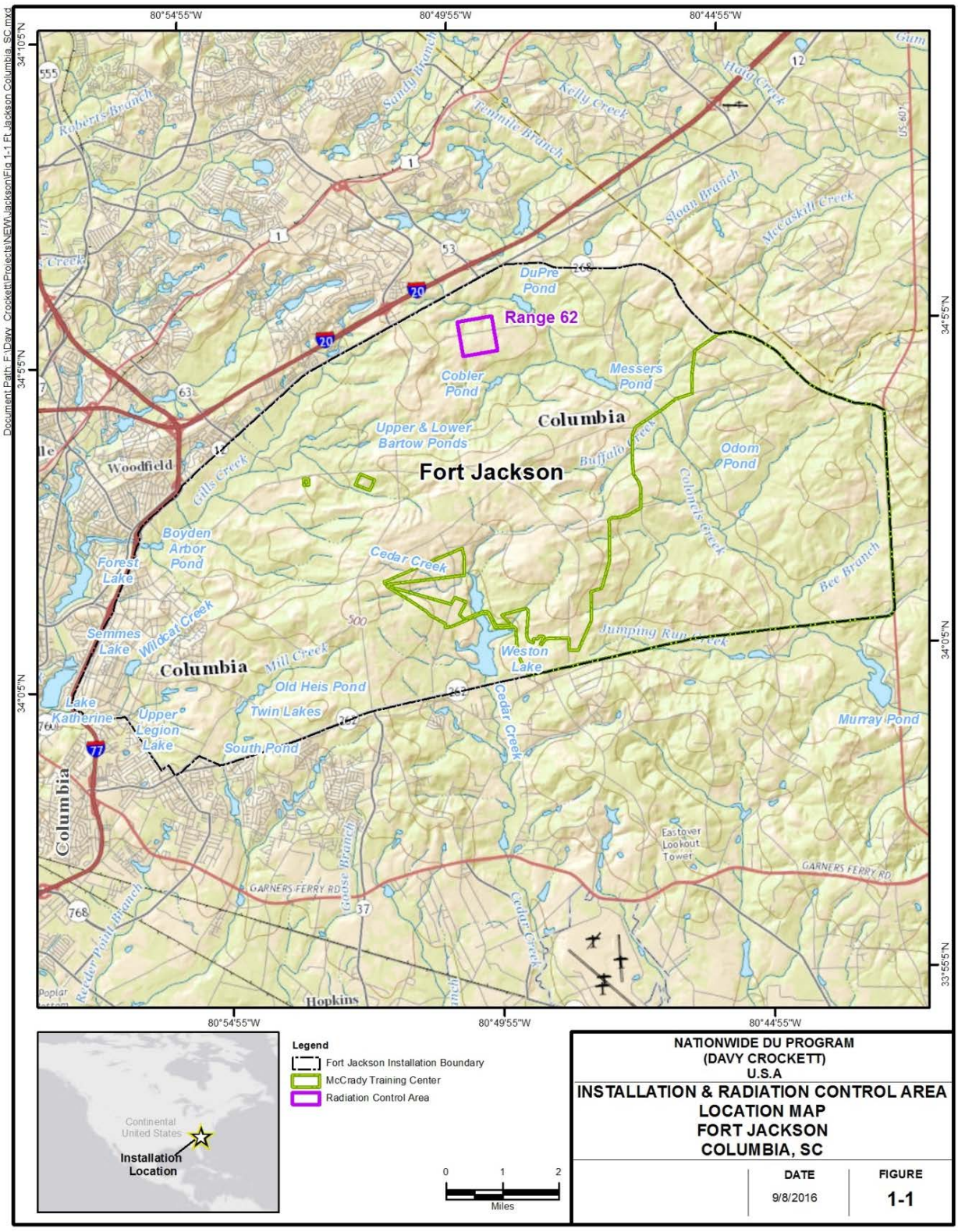

Figure 1-1. Installation and Radiation Control Area Location Map

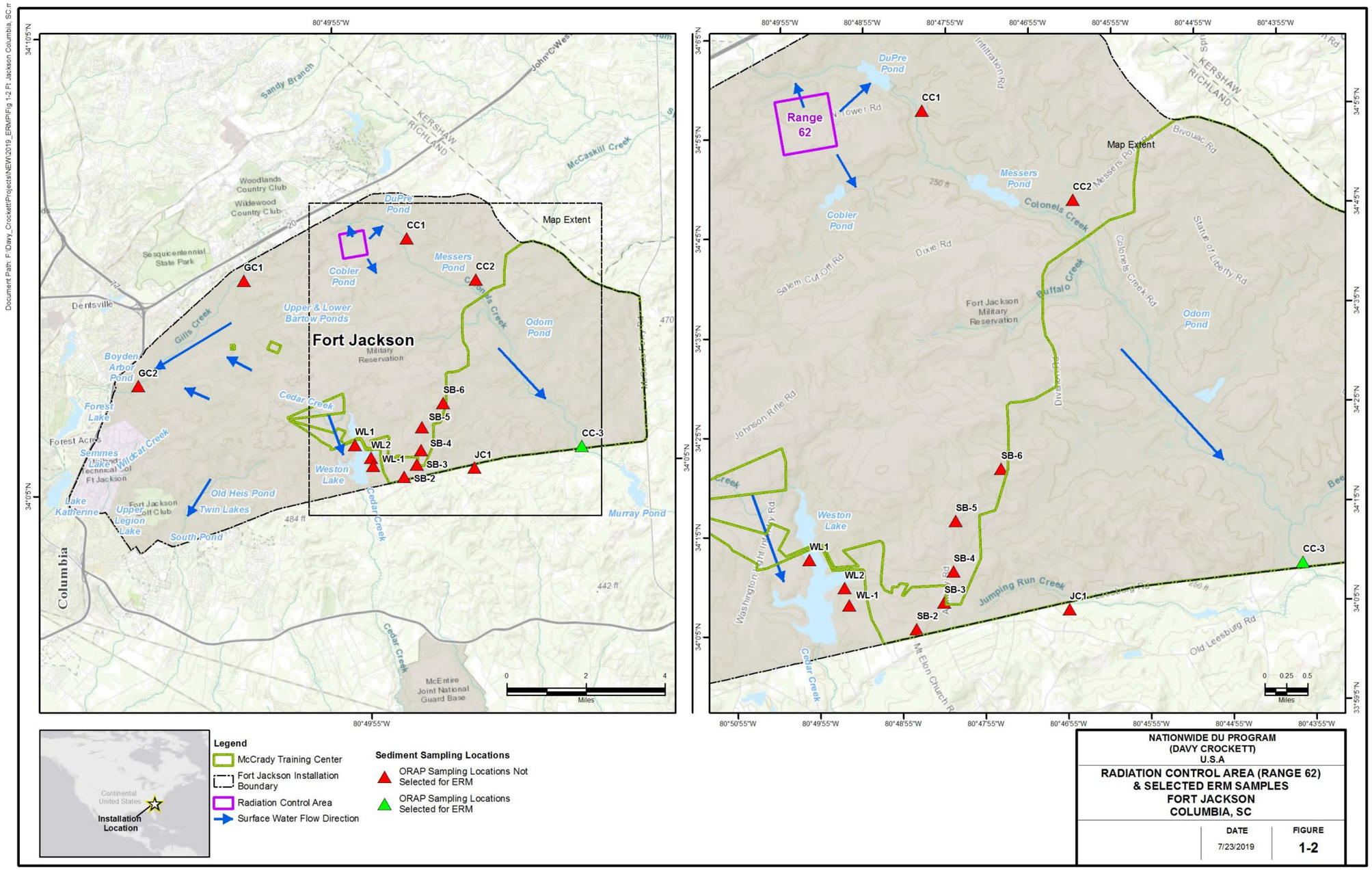

Figure 1-2. Radiation Control Area (Range 62) and Selected ERM Samples

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In addition to its training missions, the South Carolina Army National Guard (SCARNG) holds a non-exclusive license for training operations on approximately 15,267 acres of the eastern portion of Fort Jackson. These 15,267 acres at the McCrady Training Center support a variety of range uses, including live-fire weapons training, heavy and light maneuver exercises, Dudded and Non-Dudded Impact Areas, and artillery and mortar firing. McCrady Training Center is SCARNG's largest and most utilized training area, serving as the central point for state missions while also supporting Federal missions.

An Archives Search Report (ASR) (USACE 2008) confirmed the presence of one range, Range 62, at which the Davy Crockett weapon system was used in training at Fort Jackson (Figure 1-2). The historical impact area or radiation control area (RCA) for the Davy Crockett consists of 247 acres. The nearest normally occupied areas to the RCA is approximately 1.0 mile to the north-west of the RCA. Based on the conclusions of the ASR, minimal Davy Crockett weapons and 20mm spotting round debris are expected to be found on Range 62 (USACE 2008).

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapon system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the soil surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Fort Jackson; therefore, it is assumed that most, if not all, of the 30 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

The region surrounding Fort Jackson has a temperate continental climate with hot, humid summers and mild winters. This southern temperate region can experience temperatures ranging from below freezing to greater than 100 ºF; however, there is a relatively narrow annual temperature range, from a mean daily temperature of 81ºF in July to 44ºF in January (Gene Stout & Associates 2004). Average annual precipitation is approximately 46 inches. July and August are the wettest months with about approximately 5.5 inches of precipitation each month. Although July is one of the wettest months of the year with respect to precipitation, the net precipitation (i.e., precipitation less evaporation) and streamflow are low at this time of year. The evaporation potential generally exceeds precipitation during the summer months; therefore, net precipitation is highest in the winter months. Tropical storms producing heavy rainfall occasionally occur during late summer and early autumn. Wind speeds peak at approximately 9 miles per hour in spring, and the general wind direction is from the southwest. Snowfall is rare and generally results in little, if any, accumulation (U.S. Army 2014a).

Gentle to moderately rolling, moderately bisected high plains occupy most of Fort Jackson. These high plains are interrupted by the nearly flat alluvial plains of Gills, Cedar, and Colonels Creeks and their tributaries and an irregularly distributed, gently sloping, low relief area in the central portion of the installation near the headwaters of Cedar Creek. Local relief in the high plains is largely 165 to 250 feet. Slopes are predominantly 3 to 8 percent; however, along narrow stream valleys, slopes commonly exceed 15 percent. Elevations in the high plains are mostly 295 to 459 feet above mean sea level (msl). The lowest elevation in the high plains is about 200 feet, adjacent to the alluvial plain of Colonels Creek in the eastern

portion of the installation. The highest elevation, 540 feet, is at Weir Tower in the west-central portion of the installation (Gene Stout & Associates 2004). Flat to gently rolling low plains characterize the extreme western portion of the installation, including a major portion of the cantonment area and the alluvial plains occupied by southwesterly flowing Gills and Mill Creeks. Local relief around the valley of Gills Creek and its tributaries is generally less than 60 feet. Slopes are predominantly between 0 and 3 percent on the alluvial plains, and slopes in the cantonment area are predominantly between 3 and 8 percent. Upper valleys of Mill and Cedar creeks occupy low plains along the southern boundary of Fort Jackson. Local relief is generally less than 40 feet, and slopes are usually less than 3 percent (Gene Stout & Associates 2004).

Four major soil types are present at Fort Jackson: Lakeland, Vaucluse-Ailey-Pelion, Fuquay-Troup-Vaucluse, and Pelion-Johnson-Vaucluse (U.S. Army 2014a). Lakeland soils are the predominant soil type at Fort Jackson and are found at higher elevations in the central part of Fort Jackson along ridgetops (Gene Stout & Associates 2004). They consist of deep, gently to strongly sloping, and highly permeable sandy soils. Vaucluse-Ailey-Pelion soils are found along the Colonels Creek watershed in the eastern and southeastern portions of Fort Jackson. They consist of well-drained to moderately well-drained soils that have a sandy surface layer and a loamy subsoil. Fuquay-Troup-Vaucluse soils are found along Mill Creek and Cedar Creek in two small areas along the southern installation boundary. They consist of well-drained soils with sandy surface and subsurface layers and a loamy subsoil. Pelion-Johnson-Vaucluse soils are found on the western portion of Fort Jackson along the Gills Creek watershed. They consist of moderately well-drained soils that have a sandy surface layer and a loamy subsoil, very poorly drained soils that are loamy throughout, and well-drained soils that have a sandy surface layer and a fragipan in the loamy subsoil (U.S. Army 2014a, Gene Stout & Associates 2004). The high sand content of soils at Fort Jackson promotes leaching of minerals, reduced water retention, and increases susceptibility to soil erosion (USATC 2005).

The geology of South Carolina is characterized by two principal physiographic and geologic provinces: the crystalline rocks of the Piedmont physiographic province and the unconsolidated sediments of the Coastal Plain. The boundary between the Piedmont and the Coastal Plain is marked by the fall line, which occurs approximately 4 miles west and north of Fort Jackson's cantonment area (U.S. Army 2014a, Newcome 2001). Fort Jackson lies on the northwestern edge of the Coastal Plain province, a region of low to moderate relief and gently rolling plains, known as the Sand Hills. The installation sits directly on the unnamed sediments of Tertiary age and the upper Coastal Plain portion of the Cretaceous aged Middendorf Formation (Kite 1988, USGS 1994, USGS 1996). The majority of both installations sit directly on the Middendorf Formation, with Tertiary sediments locally capping uplands on the southern half of each of the installations. The Middendorf Formation (also referred to as the Tuscaloosa Formation) consists of deltaic deposits of light-colored sands and kaolin clays. Most soils at Fort Jackson are formed from sediment of the Middendorf Formation. The Middendorf Formation thickens considerably to the southeast, sitting on top of crystalline bedrock that dips to the southeast at approximately 25 feet per mile. The thickness of the unconsolidated sediments varies considerably across the installation depending on the distance from the fall line and the local topography, with total thickness of unconsolidated sediments of the Tertiary unit and Middendorf Formation varying from approximately 300 feet in the northwestern portion of Fort Jackson to approximately 500 feet in the southwestern corner of McCrady Training Center.

The Middendorf aquifer constitutes the primary aquifer used as a groundwater supply in the area including, and surrounding, Fort Jackson. Within this region, the Middendorf Formation is entirely coincident with the Middendorf aquifer. Half of the wells occurring within the Middendorf aquifer in Richland County are less than 100 feet deep. In the area directly to the south of Fort Jackson, the overwhelming majority of wells screened within the Middendorf aquifer are screened above elevations of 175 feet above msl. Wells located several miles north of the installation extract groundwater from bedrock aquifers, but very few wells on the installation or directly south of the installation extract groundwater from the bedrock aquifers due to the great depths (and therefore well installation expense) to bedrock. Depths to water on-installation and immediately downgradient (to the south) generally range from 2 to 20 feet below

ground surface (bgs) within the cantonment area and directly adjacent to streams (U.S. Army 2014a), up to a maximum depth of more than 100 feet on highlands in interstream areas near the central part of the combined installations (PIKA-Pirnie 2014a). The aquifer system in the region is described as stratified, consisting of shallow, intermediate, and deep groundwater flow systems (USGS 1996).

Fort Jackson represents an important local and regional recharge area for the Middendorf aquifer system. The majority of groundwater recharging the aquifer is expected to remain within the shallow and intermediate flow system and follow topography, ultimately discharging to local streams and rivers. A smaller proportion of recharge enters the deep groundwater flow system and discharges to regional discharge points. The Congaree and Wateree Rivers to the south and east of the installation, respectively, have been identified as regional discharge points for the deep component of the groundwater system in Richland County (USGS 1987). In addition, water infiltrating to shallow groundwater on-installation within the southern half of the combined installation generally flows in a southerly direction, as does the groundwater flow in the intermediate and deep flow systems. The area located south of the southern Fort Jackson installation boundary and west of Weston Lake is serviced by water supply infrastructure servicing Columbia and its suburbs. As such, it is unlikely that groundwater is utilized for drinking water purposes in this portion of the hydraulically downgradient area. This infrastructure does not extend to Weston Lake. Well logs obtained from Fort Jackson and the South Carolina Department of Natural Resources (SCDNR) indicated that the aquifers to the south and southeast of the installations are utilized for drinking water. Numerous groundwater supply wells are utilized to supply recreational facilities at Weston Lake. In addition, numerous residential drinking water wells and larger supply wells were identified in the area south of the combined installations and to the east of Weston Lake. During a windshield survey completed in the area, dozens of additional wells not included in the database obtained from SCDNR also were observed. Although no information is available for these wells, they are likely similarly utilized for residential drinking water as those included in the well database.

Twenty-six lakes, ponds, and impoundments are located on Fort Jackson. These water bodies range in size from 0.5 to 173 acres; however, most are less than 35 acres. Five ponds and two lakes are adequate for intensive fisheries management (Old Heises Pond, South Pond, Upper Barstow Pond, Lower Barstow Pond, Odom Pond, Upper Legion Lake, and Twin Lakes). Remaining lakes and ponds are maintained for waterfowl habitat, recreation, aesthetics, and irrigation water supply for golf courses. The largest lake, Weston Lake, is north of Leesburg Road and east of the cantonment area. The lake has a surface area of about 173 acres and accounts for more than one-third of the total impounded surface acreage for the installation. Weston Lake is also the installation's primary waterside recreation lake, with camping facilities, picnic shelters, a community house, a beach pavilion, and a swimming area (Gene Stout & Associates 2004).

Fort Jackson is located within the Santee River basin and the Congaree River subbasin. All creeks and streams leaving Fort Jackson eventually flow into either the Wateree River or the Congaree River. These rivers meet about 16 miles southeast of Fort Jackson, where they form the Santee River, the principal stream of the region. The Santee River continues in a southeasterly direction, eventually emptying into the Atlantic Ocean south of Georgetown, South Carolina (Gene Stout & Associates 2004). Fort Jackson encompasses five watersheds or subwatersheds. These watersheds are drained by Colonels, Gills, Wildcat, Mill, and Cedar Creeks, as described below.

1.4.1 Colonels Creek Watershed

The headwaters of Colonels Creek originate on Fort Jackson. This is a predominantly wooded watershed. Colonels Creek drains the eastern portion of the installation, including the Buffalo Creek area and the area licensed to the SCARNG McCrady Training Center. It flows southeast to the Wateree River, a tributary of the Congaree River. The Colonels Creek watershed serves as the primary watershed for the Range 62.

1.4.2 Gills Creek Watershed

Gills Creek, in the northwestern portion of Fort Jackson, drains the small arms ranges and western impact area, as well as non-live-fire training areas, and flows into Boyden Arbor Pond before resuming downstream from the installation. Gills Creek drains a primarily forested watershed on Fort Jackson and a predominantly urban watershed downstream from Fort Jackson. Gills Creek, downstream from Fort Jackson, is listed as impaired for fecal coliform and dissolved oxygen on South Carolina's 2012 Clean Water Act Section 303(d) list of water quality limited segments (Gene Stout & Associates 2004, SCDHEC 2012). The U.S. Geological Survey (USGS) maintains a stream gauge on Gills Creek downstream from Fort Jackson within the city of Columbia. Since evapotranspiration has a strong influence on stream flow rate within Gills Creek, months with the highest precipitation do not correspond to the months with the highest stream flow rate. This is consistent with conditions common in forested areas of the southeastern United States.

1.4.3 Wildcat Creek Watershed

Wildcat Creek drains a small portion of the cantonment area and flows to the west, where it enters Gills Creek just below Lake Katherine. None of the operational range areas are drained by Wildcat Creek.

1.4.4 Mill Creek Watershed

Mill Creek drains an area in the southwestern portion of the training areas and flows off-post to the south, where it eventually enters the Congaree River. The Mill Creek watershed encompasses a small area in the southern portion of the Non-Dudded Impact Area (including two small arms ranges), wooded training areas, and the Twin Lakes Recreational Area located on-post.

1.4.5 Cedar Creek Watershed

Cedar Creek drains the majority of a large Dudded Impact Area and flows southward through the Weston Lake Recreation Area, eventually entering the Congaree River.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERCATIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCA at Fort Jackson are as follows:

- ***Surface Water Use***—Surface water on and surrounding Fort Jackson includes sensitive environments, habitats, and ecological receptors.
- ***Recreational Use***—Twenty-six lakes, ponds, and impoundments are located on Fort Jackson, ranging in size from 0.5 to 173 acres with most being less than 35 acres. Five ponds and two lakes are adequate for intensive fisheries management (Old Heises Pond, South Pond, Upper Barstow Pond, Lower Barstow Pond, Odom Pond, Upper Legion Lake, and Twin Lakes). Remaining lakes and ponds are maintained for waterfowl habitat, recreation, aesthetics, and irrigation water supply for golf courses. Potential human receptors include recreational users of Lake Katherine, Murray Pond, and Forest Lake.
- ***Sensitive Environments and Habitats***—Sensitive environments and habitat exist on or around Fort Jackson, including those that support critical animal and plant species. Two federally listed endangered plant species, rough-leaved yellow loosestrife (*Lysimacia asperulaefolia*) and smooth purple coneflower (*Echniacea laevigata*), occur at or near Fort Jackson. Each of these species is listed as imperiled statewide. In addition, one federally listed endangered animal, the

red-cockaded woodpecker (*Picoides borealis*), is a resident of Fort Jackson. Two additional federally endangered species, the shortnose sturgeon (*Acipenser brevirostrum*) and Canby's dropwort (*Oxypoliscanbyi*), are found in the vicinity of Fort Jackson.

- ***Groundwater Use***—Groundwater downgradient from the installation is used for public and private drinking water supplies. There are community and private wells around Range 62 but not proximal to the range. In addition, Fort Jackson is an important local and regional source of groundwater recharge for the Middendorf aquifer system (PIKA-Pirnie 2014a,b and Malcolm Pirnie 2009).

Potential human receptors include those within Fort Jackson that rely on potential public and private wells and surface waters downstream from the RCA. Groundwater wells downgradient from the RCA are subject to use as a drinking water source. Ecological receptors include sensitive environments (e.g., wetlands and anadromous fish habitat) and endangered plant and animal species.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Range 62 RCA at Fort Jackson are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the collection of one sample from a location downstream from the Range 62 RCA where surface water generally flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling location at Fort Jackson was selected based on the surface water hydrology downstream from Range 62, the location of Range 62, and potential for DU contribution. It is located as follows:

- ***CC3***—The selected sampling point is located on Colonels Creek southeast of the RCA and is located downstream from the RCA. This sample location is also near the boundary between Fort Jackson and the McCrady Training Center

Additional locations were sampled during the Operational Range Assessment Program (ORAP) Phase II assessment (Figure 1-2) and ORAP Phase II assessment did not include radiological parameters (U.S. Army 2014a). These locations were not selected for evaluation of the Range 62 RCA based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***GC-1***—The sampling point is located about 2 miles west-southwest of the RCA and about 1 mile south of Interstate Highway 70. The area represented by this sample would include largely runoff from the Gills Creek watershed, but the RCA is not located within this watershed.
- ***GC-2***—The sampling point is located along Gills Creek about 5 miles southwest of the RCA and is serviced by the Gills Creek watershed. The RCA is not located within this watershed.
- ***WL-1 and WL-2***—The sampling points are located along Weston Lake about 5 miles south of the RCA.
- ***CC-1***—The sampling point is within the Colonels Creek watershed where the RCA is located, but is not at a location receiving runoff from the RCA.
- ***CC-2***—The sampling point is within the Colonels Creek watershed where the RCA is located, but is not at a location receiving runoff from the RCA.
- ***JC-1***—The sample location is about 6 miles south of the RCA and east of Weston Lake. This sample location is also near the boundary between Fort Jackson and the McCrady Training Center.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are

presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-283)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for Fort Jackson, South Carolina, Annex 9 (ML16265A243) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, CC3, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the Environmental Radiation Monitoring (ERM) sampling events at Fort Jackson are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
CC-3	5/25/2017	ND
CC-3	8/31/2017	ND
CC-3	11/27/2017	ND
CC-3	4/3/2018	ND
CC-3	6/5/2018	0.39 +/- 0.38
CC-3	9/11/2018	ND
CC-3	12/11/2018	ND

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
CC-3	5/25/2017	1.1 +/- 0.5
CC-3	8/31/2017	0.88 +/- 0.25
CC-3	11/27/2017	1.0 +/- 0.3
CC-3	4/3/2018	0.92 +/- 0.23
CC-3	6/5/2018	0.95 +/- 0.28
CC-3	9/11/2018	0.78 +/- 0.19
CC-3	12/11/2018	0.91 +/- 0.2

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at Fort Jackson.

2.2 GROUNDWATER

Three rounds of groundwater samples were collected from July 2012 to February 2013 (total of 36 groundwater samples). These samples were analyzed for explosives and uranium and the results are summarized in Table 2-3. Uranium was detected in 1 of the 36 samples at a concentration of 0.46 micrograms per liter (µg/L) or 1.5 percent of the U.S. Environmental Protection Agency's (USEPA's) Safe Drinking Water Act (SDWA) maximum contaminant level (MCL) (i.e., USEPA drinking water standard of 30 µg/L for uranium). Isotopic ratios could not be measured given the lack of sufficient activity information for one or more isotopic constituents. The lower limit of range of uncertainty (µg/L) for uranium is reported as 3.0 µg/L.

Table 2-3. Groundwater Uranium Concentrations

Sample Location	Uranium Concentration (µg/L)
MW-RS-02S	0.46
MW-RS-02D	Non-detect
MW-RS-03S	Non-detect
MW-RS-03D	Non-detect
MW-RS-04S	Non-detect
MW-RS-04D	Non-detect
MW-RS-05S	Non-detect
MW-RS-05D	Non-detect
MW-RS-06S	Non-detect
MW-RS-06D	Non-detect
MW-RS-07S	Non-detect
MW-RS-07D	Non-detect

Presently, no groundwater monitoring wells are located at or near the RCA. In addition, groundwater in the shallowest aquifer discharges to the adjacent surface water bodies for the majority of the installation. Since shallow groundwater is known to discharge to surface water, any DU potentially present in groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Jackson.

2.3 SOIL

If an area of soil greater than 25 square meters (m2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), garrison safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014b]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Jackson does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Jackson will be coordinated with the Fort Jackson Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 mass content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate the total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235 or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (30 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Jackson RCA

Parameter		Default Value	Fort Jackson Range 62	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	2.95×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	2.7×10^{-4}	
	U-238	N/A	0.04	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 2 to 20 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand (Soil is loamy sand from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	6.9	**www.usa.com** for Fort Jackson, SC
Precipitation rate (annual rainfall) (m/y)		1.0	1.2	**www.usa.com** for Fort Jackson, SC
Saturated Zone				
Saturated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Jackson RCA

RCA Layout Parameter	Fort Jackson Range 62			
Distance to nearest normally occupied area (m)	1,600			
Bearing of X axis (degrees)	45 (northwest)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	2700	2732
Leafy vegetables plot	500	531.25	2734	2766
Pasture, silage growing area	500	600	2916	3016
Grain fields	500	600	2766	2866
Dwelling site	500	531.25	2600	2632
Surface-water body	500	800	3016	3316
Atmospheric Transport Parameter				
Meteorological STAR file	SC_COLUMBIA.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	1,600			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	2,016			
Distance to well (perpendicular to aquifer flow)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	225			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for the RCA evaluated at Fort Jackson does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Jackson Range 62	4.7×10^{-3}	4.1×10^{-3}

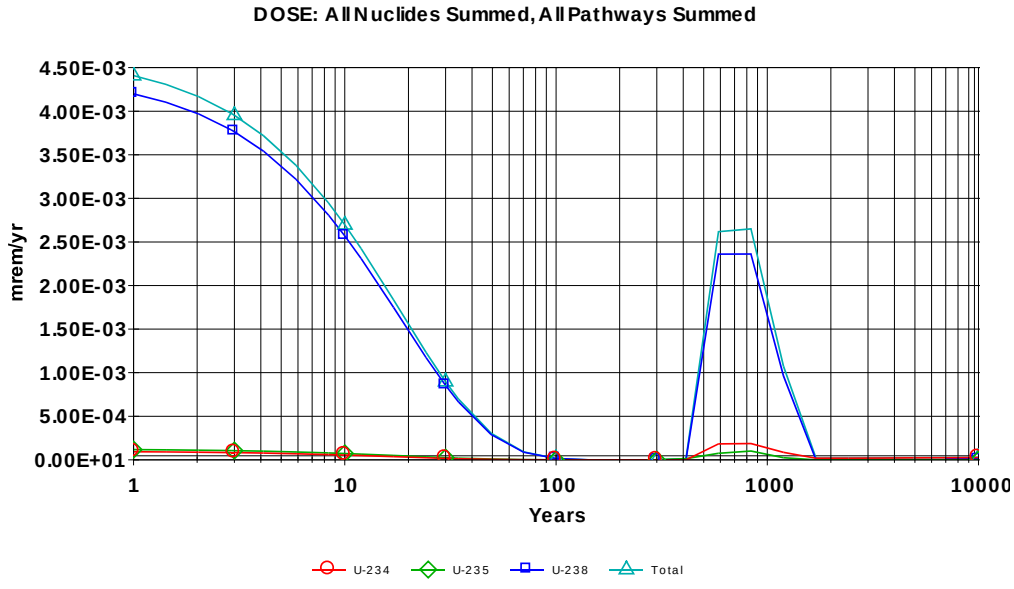
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

Figure 4-1. Residential Farmer Receptor Dose Graphs

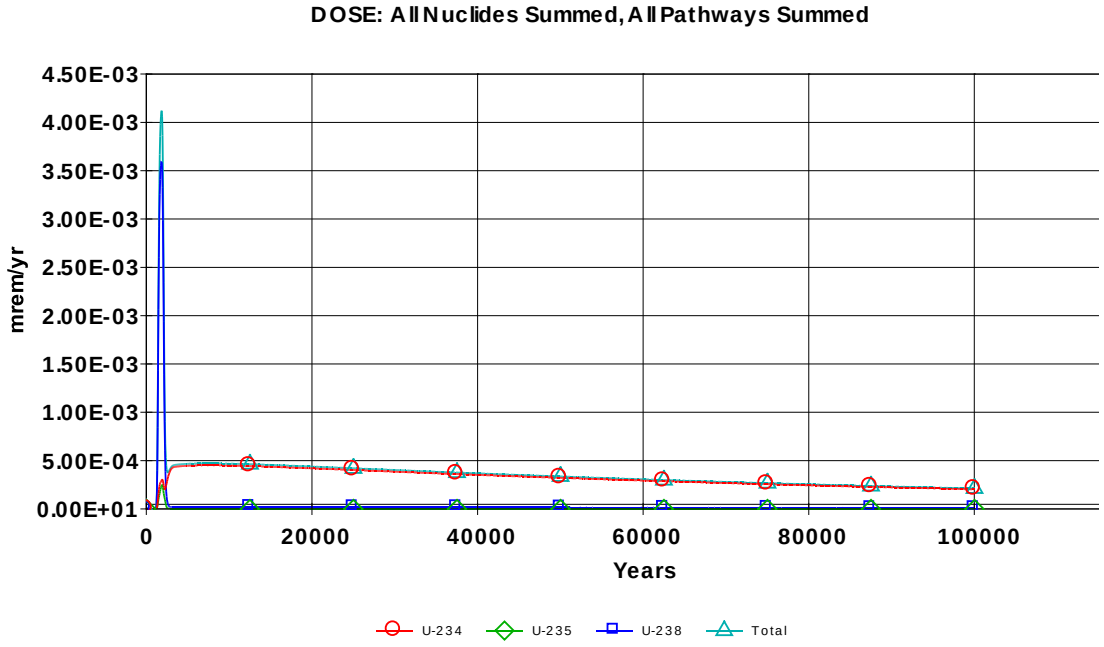
Fort Jackson Range 62

RCA Onsite (RESRAD)



C:\RESRAD_FAMILY\RESRAD\7.0\USERFILES\FORT JACKSON RANGE62.RAD 08/30/2016 08:52 GRAPHICS.ASC Includes All Pathway:

RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT KNOX, KENTUCKY ANNEX 10

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
BRAC	Base Realignment and Closure
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mSV/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMP (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Knox, Kentucky, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Knox, Kentucky, Annex 10 (ML16265A224) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Knox. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment sample downstream (**SWS-03**) from the O'Brien and Arms Knobs Ranges RCAs, as shown in Figures 1-2 and 1-3 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Fort Knox is a 110,000-acre installation located in north-central Kentucky, directly south of the Ohio River and 30 miles southwest of Louisville (Figure 1-1). The installation has an operational footprint of 99,003 acres and includes 207 ranges (EA 2012).

Fort Knox was initially established as Camp Knox, a World War I training center in 1918. In 1932, Congress designated the installation as a permanent garrison and renamed it Fort Knox. The installation's military activities were expanded during World War II, and its total area was increased to approximately 110,000 acres by 1943. The Armored Combat Division transferred to Fort Knox in 1955. Since 1955, the installation's principal mission has been basic combat training and advanced individual training in armored vehicles. In 2005, the Base Realignment and Closure (BRAC) Commission initiated the relocation of the Armor Center and School and Infantry Center to Fort Benning (EA 2014).

The impact areas where the Davy Crockett weapons system was used at Fort Knox comprise two radiation control areas (RCAs) (Figures 1-2 and 1-3). The nearest normally occupied areas to the O'Brien Range RCA is a small arms shooting range, which is located approximately 0.7 miles to the southwest of the RCA. The nearest normally occupied areas to the Arm Knobs Ranges RCA is a private residence, which is located approximately 1 mile southeast of the RCA.

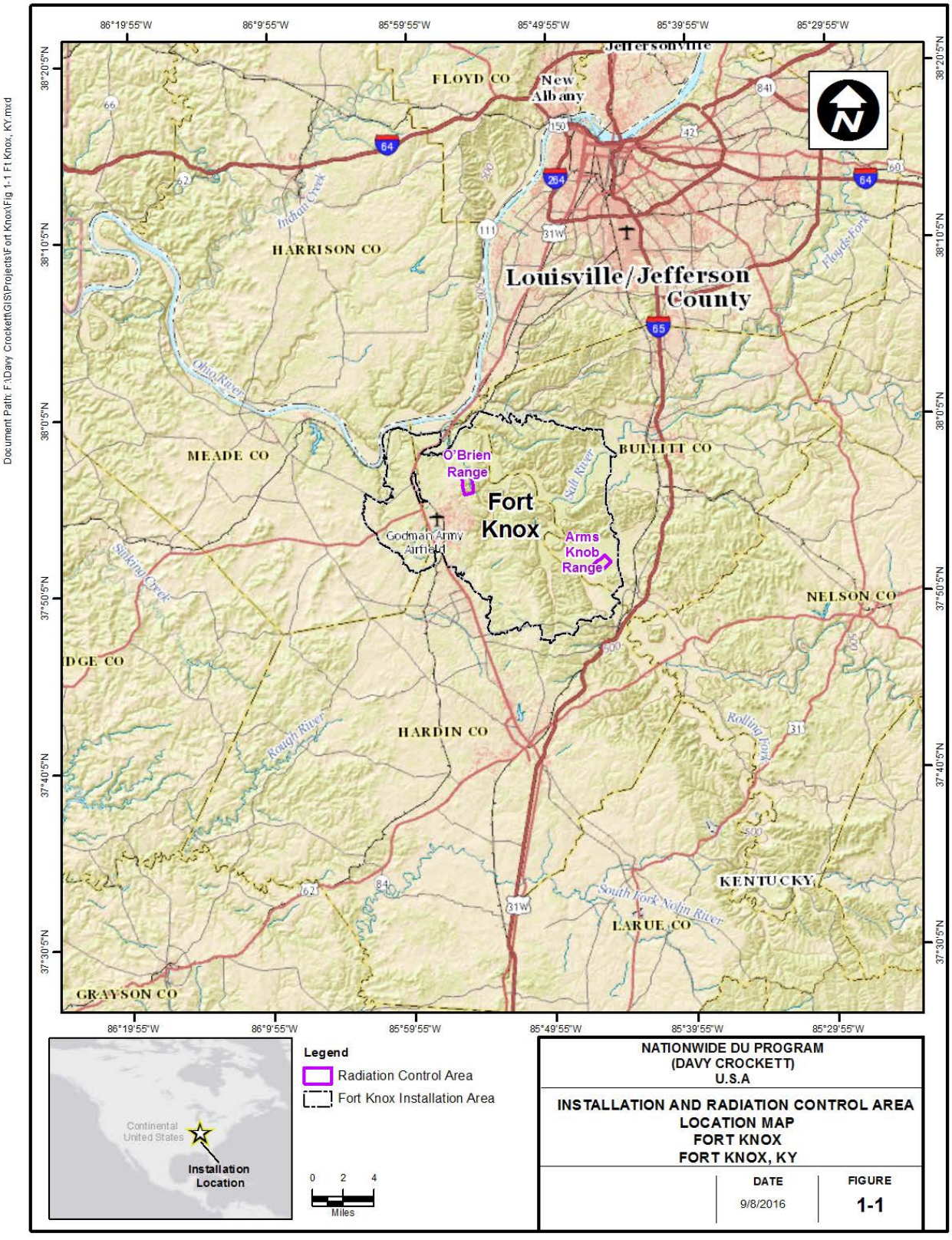

Figure 1-1. Installation and Radiation Control Area Location Map

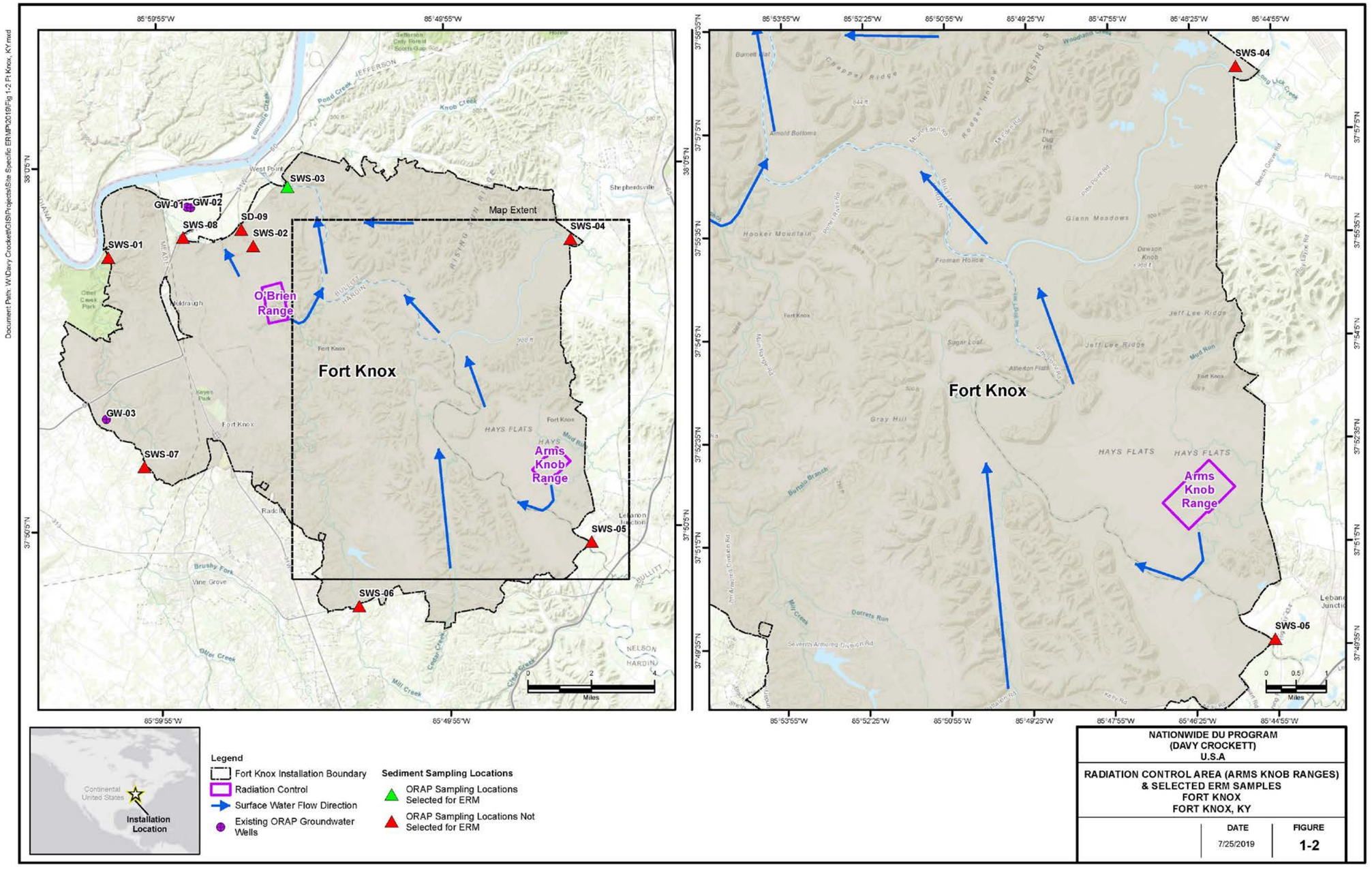

Figure 1-2. Radiation Control Area (Arms Knob Ranges) and Selected ERM Samples

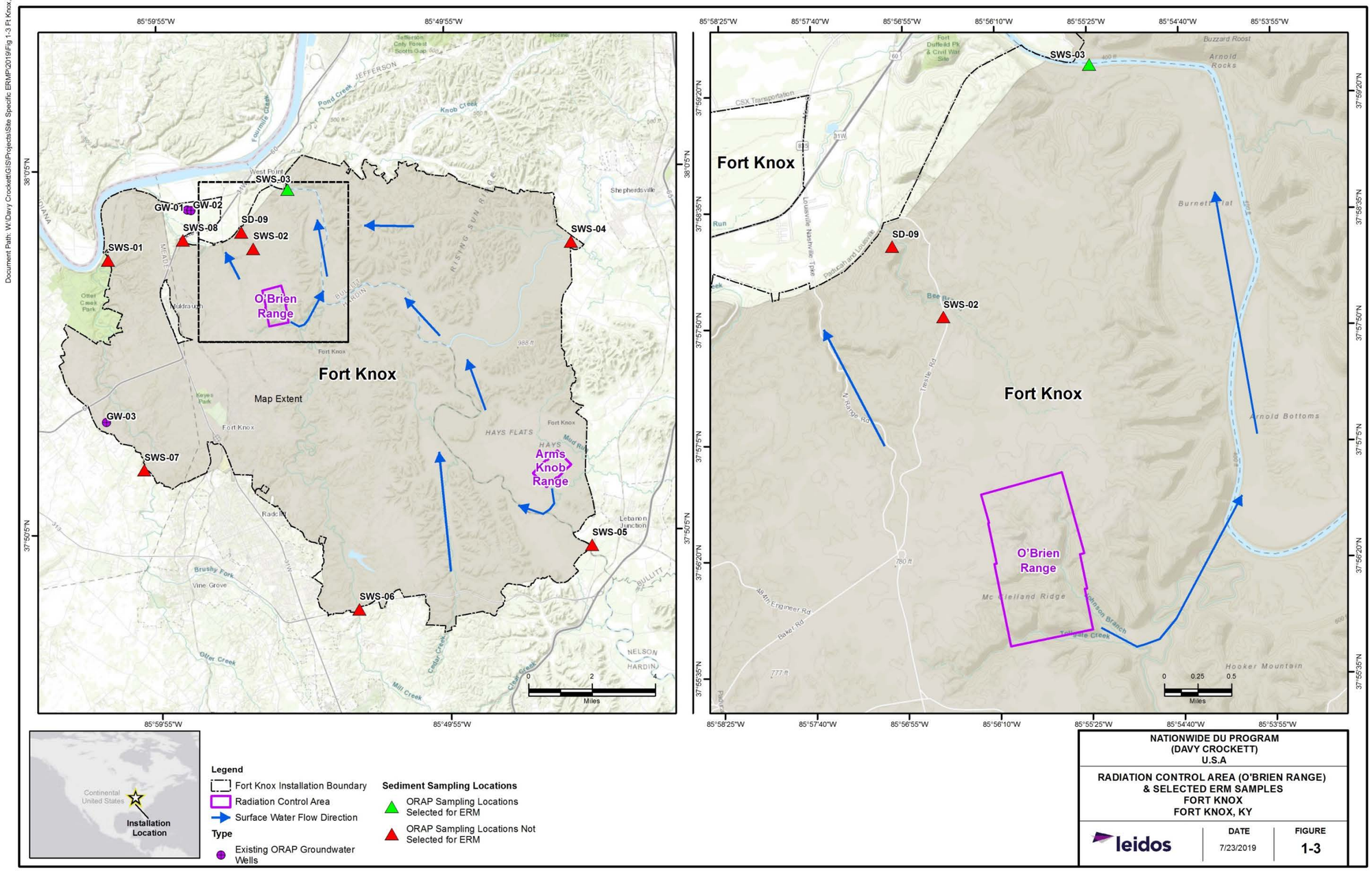

Figure 1-3. Radiation Control Area (O'Brien Range) and Selected ERM Samples

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Fort Knox; therefore, it is assumed that most, if not all, of the 760 kilograms (kg) of DU (SUC-1593) from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Fort Knox overlays four distinct physiographic provinces: the Ohio River Valley, the Pennyroyal area of the Mississippi Plateau, the Knobs subdivision of the Blue Grass Region, and the Outer Blue Grass subdivision of the Blue Grass Region. The installation is generally characterized by flat to gently-rolling topography (EA 2014), as described below:

- The northwestern-most portion of Fort Knox is overlain by the Ohio River Valley alluvial deposits typical of floodplains. Deposits are flat-lying and range from several feet to several miles in width and from several feet to several hundred feet thick. Quaternary alluvium composed of silt, clay, sand, and gravel is present along the Ohio River and the major drainage basins at Fort Knox. The alluvium and outwash deposits along the Ohio River near the town of West Point, Kentucky, and reach thicknesses of approximately 120 feet, while deposits within the smaller basins (e.g., Salt River, Mill Creek, and Rolling Fork) are typically 10 to 20 feet thick.
- The remaining western portion of Fort Knox lies within the Pennyroyal area of the Mississippi Plateau and consists of a highly developed karst landscape dotted with sinkhole depressions. Surface water features within this portion of the installation are poorly developed due to the maturity of the karst features. The uppermost bedrock is the Mooretown Sandstone. The underlying Mississippian St. Louis Limestone is the predominant karst-forming formation in the western portions of Fort Knox. The unit is between 70 to 230 feet thick composed of coarsely crystalline, fine-grained, gray to tan limestone with sparse amounts of gypsum. Dissolution of the St. Louis Limestone results in the formation of sinkholes, which provide a direct link to shallow groundwater overlying the Salem Limestone. The Salem Limestone is an approximately 80- to 130-foot-thick crystalline and fossiliferous limestone with a brown to gray color and interbedded clayey limestone and shale deposits. The upper part of the Salem Limestone exhibits a spring horizon where water entering the groundwater vertically through the overlying St. Louis Limestone intersects a siliciclastic lens within the Salem Limestone and migrates laterally toward Otter Creek until it discharges along incised surface water drainages.
- The eastern portion of Fort Knox is located within two physiographic provinces: the Outer Blue Grass subdivision and the Knobs subdivision of the Blue Grass Region. The Knobs subdivision is on the western/southwestern periphery of the Outer Blue Grass subdivision. Bedrock below the eastern portion of Fort Knox is composed of the Harrodsburg Limestone and Borden Formation, which represent the Lower Mississippian age deposits. These formations contain

siliciclastic lenses, similar to those in the Salem Limestone, which inhibit the formation of karst features and result in significant runoff. The Harrodsburg Limestone is between 20 and 70 feet thick, and the Borden Formation is approximately 100 feet thick below the installation.

Two primary drainage basins on Fort Knox are the Salt River Basin and the Otter Creek Basin. Both of these watersheds feed into the Ohio River along the northwestern installation boundary. The Salt River Basin drains approximately 70 percent of the installation, encompassing the central and eastern portions of Fort Knox, including both of the RCAs. The Bee Branch, Rolling Fork, Mill Creek, and Crooked Creek are part of the Salt River watershed. The surface water drainage network in the Salt River Basin is much more extensive due to the limited karst terrane (Figures 1-2 and 1-3). Abrahams Run and Tioga Creek form a small watershed at the northern tip of the installation that drains to the Ohio River in between the Salt River and Otter Creek.

The majority of the groundwater beneath Fort Knox occurs as an unconfined aquifer in the limestone bedrock. Other groundwater underlying the installation occurs in the quaternary alluvium lining the floodplains of the Ohio River and other major streams and rivers. Much of the western portion of Fort Knox is dominated by karst features, such as losing streams, sinkholes, and springs created by physical and chemical weathering of the limestone bedrock. Recharge in the karst terrane occurs through losing streams and sinkholes. Groundwater in the eastern portion of the installation occurs deep in the bedrock, moving through cracks and fractures. The bedrock aquifer is recharged through precipitation and surface water infiltration.

Based on dye tracer tests that are nearest the RCAs, the groundwater flow is to the northwest (EA 2012, Figure 10-2). The Fort Knox well field, now owned by the Louisville Water Company, lies in the alluvial deposits of the cut-off meander just north of the installation boundary in the Ohio River floodplain. Recharge of this aquifer occurs primarily from rainfall infiltration and discharge from the limestone plateau in the south. Groundwater flow in the non-karst limestone moves north toward the Ohio River, and discharge locations include the Ohio River, water supply wells, and the underlying bedrock aquifer.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCAs at Fort Knox are as follows:

- ***Surface Water Use***—Surface water on and surrounding Fort Knox, including the Salt River and Otter Creek, contain sensitive environments, habitats, and ecological receptors. With respect to the Salt River and Otter Creek, public drinking water intakes are not located on or downstream from Fort Knox. With respect to the Ohio River, public drinking water intakes are not located downstream from Salt River and Otter Creek for more than a hundred river miles.
- ***Recreational Use***—Recreational activities occurring on and around Fort Knox include designated swimming areas within Otter Creek Park, just northwest of Fort Knox.
- ***Sensitive Environments***—Natural areas of Fort Knox provide unique habitat for sensitive flora and fauna, including Cedar Glades; Ohio River Bottomland Hardwood Swamp; Otter Creek Ravines; Otter Creek Corridor; Grahamton Cave; karst ponds west of Otter Creek; Godman Army Airfield; Ohio/Salt River Tributary Ravines; and floodplains and lower slopes along the Salt River, Rolling Fork, and Lower Mill Creek. Fort Knox includes approximately 738 acres of riverine wetlands, 1,335 acres of plasturine wetlands, and 237 acres of lacustrine wetlands that are ecologically and hydrologically significant, and perform flood/flow retention, nutrient trapping, and carbon export. Most of this habitat lies in operational range area; however, it is

possible that similar habitat can exist in nearby off-range locations. Wetlands and other sensitive environments located off-range within 15 miles downstream from active ranges are considered potential ecological receptors.

- ***Habitat***—Karst terrane occurs on and west of Fort Knox and consists of caves, karst ponds, and ravines. This, along with the floodplains of the Salt River, Rolling Fork, and Lower Mill Creek in the northern part of Fort Knox, provide habitat for sensitive flora and fauna.
- ***Ecological Receptors***—State-listed threatened and endangered plants found around Fort Knox include the Allegheny Stonecrop, Compass Plant, Great Plains Ladies' Tresses, Large Sedge, Drooping Bluegrass, and Tall Beaked-Rush. In addition, state and federally listed threatened and endangered animals known to occur around Fort Knox include the Gray Bat, Indiana Bat, Bald Eagle, and Cave Crayfish.
- ***Groundwater Use***—Groundwater receptor wells include 13 water supply wells (4 on-installation and 9 off-installation) located north of the installation in the Ohio River floodplain. Water from these wells is supplemented with water from a surface water intake on Otter Creek, adjacent to McCracken Spring, and comprises the primary water supply for the installation. Currently, only two wells are located within the Fort Knox well field that are in use by the Louisville Water Company. Public water supply for the Hardin County Water District and the city of West Point is provided by wells in the alluvium near the Fort Knox well field.

Potential human receptors include those within Fort Knox, West Point, and Hardin County who rely on potable water from wells within the Fort Knox well field or from Otter Creek. Ecological receptors include sensitive environments (e.g., wetlands, natural areas, and endangered species).

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCAs at Fort Knox are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of a sample from a location downstream from the RCAs near the installation boundary for Fort Knox (Figures 1-2 and 1-3) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling location at Fort Knox was selected based on the surface water hydrology of the Salt River, Otter Creek, and Abrahams Run/Tioga Creek watersheds; the locations of the two RCAs; and the potential for DU contribution, as follows:

- ***SWS-03***—This selected sampling point is located on the Salt River at the installation's northern boundary. The sampling point is also upstream of mixing from inflow from the Ohio River. This sampling point is downstream from the portion of the Salt River watershed where the RCAs are located.

Additional locations sampled during the U.S. Army Operational Range Assessment Program (ORAP) Phase II assessment (Figures 1-2 and 1-3), but were not selected for evaluation of the Fort Knox RCAs based on the surface water hydrology and potential for DU contribution include:

- ***SWS-01***—This surface water sampling point is located on Otter Creek, downstream from the installation's northern boundary and downstream from where a small tributary from the installation enters Otter Creek. The sampling point is also upstream of mixing from inflow from the Ohio River. This sampling point is not relevant because the RCAs are not within the Otter Creek watershed.
- ***SWS-02***—This surface water sampling point is located on the Bee Branch that flows to the Salt River near where the Salt River enters the Ohio River. The watershed for the Bee Branch is separated by a ridge from the watershed for the Johnson Branch of Mill Creek where the O'Brien Range RCA is located. Because of the ridge, the Bee Branch does not receive surface water from an RCA. This sampling point is not relevant because the RCAs are not within the Bee Branch watershed.
- ***SD-09***—This sediment sampling point is located on the Bee Branch. The watershed for the Bee Branch is on the other side of a ridge where the O'Brien Range RCA is located, so the Bee Branch does not receive surface water from an RCA. This sampling point is not relevant because the RCAs are not within the Bee Branch watershed.

- ***SWS-04, SWS-05, SWS-06, SWS-07, SWS-08***—These surface water and sediment sampling points are located on the Salt River, Rolling Fork, Mill Creek, Otter Creek, and Tioga Creek, respectively, where they enter the installation. These background/reference sampling locations are not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCAs indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The selected downstream sampling location, SWS-03, for the environmental radiation monitoring (ERM) and the additional ORAP Phase II assessment sample locations, SWS-02, SWS-04, SWS-05, SWS-06, and SWS-08, were sampled in 2012, 2013, and 2014 and analyzed for uranium in surface water and sediment (EA 2014). The range of U-238/U-234 activity ratios from the September 2012, March and April 2013, and March 2014 sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2012, 2013, and 2014 ORAP Phase II Assessment

Sample Location[a]	Number of Samples	U-238/U-234 Ratio Range[b] (unitless)
SWS-02	4	0.81 to 1.23
SWS-03	4	ND to 0.90
Reference SWS-04	4	ND to 1.25
Reference SWS-05	4	ND to 1.31
Reference SWS-06	4	ND to 0.90
Reference SWS-08	4	0.93 to 1.19

[a] Samples from SD-09 were not submitted for analysis of uranium activity ratios based on the results from SWS-02.
[b] The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

In accordance with the Site-Specific ERMP for Fort Knox, Kentucky, Annex 10 (ML16265A224) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, SWS-03, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Knox are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2012, 2013, and 2014 ORAP Phase II Assessment

Sample Location[a]	Number of Samples	U-238/U-234 Ratio Range[b] (unitless)
SWS-01	2	ND to 0.90
SWS-02	3	0.81 to 1.15
SWS-03	3	ND to 0.90
Reference SWS-04	3	ND to 1.25
Reference SWS-05	3	ND to 1.31
Reference SWS-06	3	ND to 0.90
Reference SWS-07	2	ND to 0.81
Reference SWS-08	3	0.93 to 1.19

[a] Samples from SD-09 were not submitted for analysis of uranium activity ratios based on the results from SWS-02.
[b] The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-03	5/24/2017	0.78 +/- 0.33
SWS-03	8/29/2017	0.13 +/- 0.04
SWS-03	11/29/2017	0.64 +/- 0.42
SWS-03	3/6/2018	0.50 +/- 0.28
SWS-03	5/30/2018	0.62 +/- 0.28
SWS-03	9/11/2018	0.93 +/- 0.05
SWS-03	11/27/2018	0.38 +/- 0.27

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-03	5/24/2017	0.52 +/- 0.21
SWS-03	8/29/2017	1.1 +/- 0.3
SWS-03	11/29/2017	1.1 +/- 0.3
SWS-03	3/6/2018	1.2 +/- 0.3
SWS-03	5/30/2018	0.96 +/- 0.22
SWS-03	9/11/2018	0.90 +/- 0.19
SWS-03	11/27/2018	1.2 +/- 0.3

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4. U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Knox.

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment in September 2012 and March 2013 were analyzed for uranium (EA 2014). The U-238/U-234 activity ratios from these sampling events are presented in Table 2-5. The existing groundwater monitoring wells are shown in Figure 1-2.

Table 2-5. U-238/U-234 Activity Ratios for Groundwater Samples Collected During the 2012 and 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
GW-01	2	0.67-1.08
GW-02	1	0.89
GW-03	2	ND to 0.69

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Presently, no groundwater monitoring wells are located at or near the RCAs. Groundwater in the shallowest aquifer flows toward the Ohio River away from the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Knox.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Knox does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Knox will be coordinated with Fort Knox Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD 7.2) (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (i.e., 760 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries. That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Knox RCAs

Parameter		Default Value	Fort Knox O'Brien Range	Fort Knox Arms Knob Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone					
Soil concentrations (pCi/g)	U-234	N/A	7.48×10^{-2}	4.37×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass * nuclide specific mass abundance[a] * nuclide specific activity[a] / (CZ area * CZ depth * CZ density)
	U-235	N/A	6.48×10^{-3}	4×10^{-3}	
	U-238	N/A	1.13	0.66	
Area of contaminated zone (m^2)		10,000	1,000,000	1,710,000	
Depth of contaminated zone (m)		2	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	Depth to groundwater is generally 10 to 30 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	Groundwater flows westward across RCA
Contaminated zone total porosity		0.4	0.42	0.42	RESRAD Manual Table E-8 (DOE 2001) for Clay (Soil is silty clay from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	32.6	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Contaminated zone b parameter		5.3	10.4	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Average annual wind speed (m/s)		2.0	7.4	7.4	**www.usa.com** for Fort Knox, KY
Precipitation rate (annual rainfall) (m/y)		1.0	1.3	1.3	**www.usa.com** for Fort Knox, KY
Saturated Zone					
Saturated zone total porosity		0.4	0.42	0.42	RESRAD Manual Table E-8 (DOE 2001) for Clay
Saturated zone effective porosity		0.2	0.06	0.06	RESRAD Manual Table E-8 (DOE 2001) for Clay
Saturated zone hydraulic conductivity (m/y)		100	32.6	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Saturated zone b parameter		5.3	10.4	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Unsaturated Zone					
Unsaturated zone 1, total porosity		0.4	0.42	0.42	RESRAD Manual Table E-8 (DOE 2001) for Clay
Unsaturated zone 1, effective porosity		0.2	0.06	0.06	RESRAD Manual Table E-8 (DOE 2001) for Clay
Unsaturated zone 1, soil-specific b parameter		5.3	10.4	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Unsaturated zone 1, hydraulic conductivity (m/y)		10	32.6	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Knox RCAs

RCA Layout Parameter	Fort Knox O'Brien Range				Fort Knox Arms Knob Range			
Distance to nearest normally occupied area (m)	1,100 (southwest)				1,600 (southeast)			
Bearing of X axis (degrees)	315				225			
X dimension of primary contamination (m)	1,000				1,710			
Y dimension of primary contamination (m)	1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	2200	2232	855	886.25	2700	2732
Leafy vegetables plot	500	531.25	2234	2266	855	886.25	2734	2766
Pasture, silage growing area	500	600	2416	2516	855	955	2916	3016
Grain fields	500	600	2266	2366	855	955	2766	2866
Dwelling site	500	531.25	2100	2132	855	886.25	2600	2632
Surface-water body	500	800	2516	2816	855	1155	3016	3316
Primary Contamination Parameter								
Length parallel to aquifer flow*	105				105			
Atmospheric Transport Parameter								
Meteorological STAR file	KY_LOUISVILLE.str				KY_LOUISVILLE.str			
Groundwater Transport Parameter								
Distance to well (parallel to aquifer flow) (m)	1100				1600			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1516				2016			
Distance to well (perpendicular to aquifer flow) (m)	0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	135				45			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Knox does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Knox O'Brien Range	0.36	0.060
Fort Knox Arms Knob Range	0.22	0.036

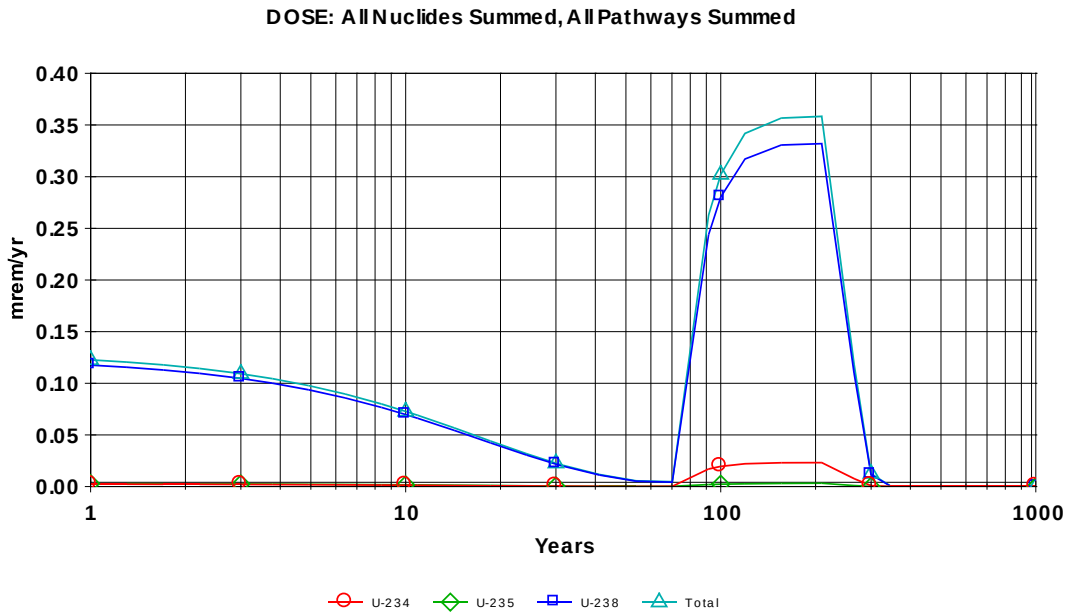
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

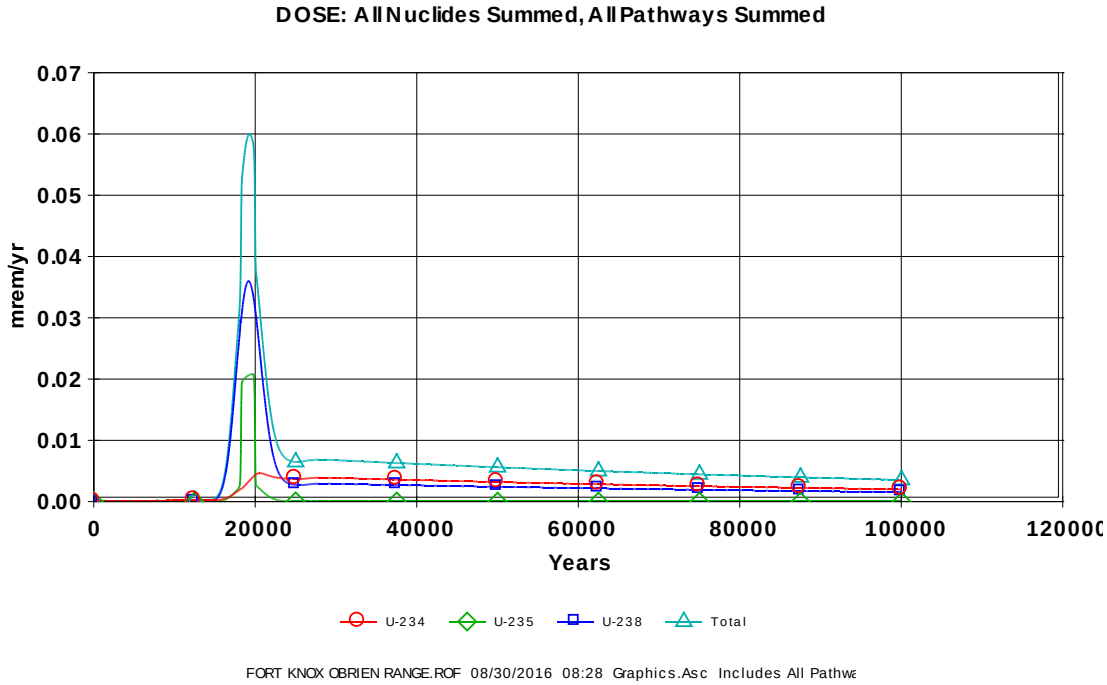
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Knox O'Brien Range

RCA Onsite (RESRAD)

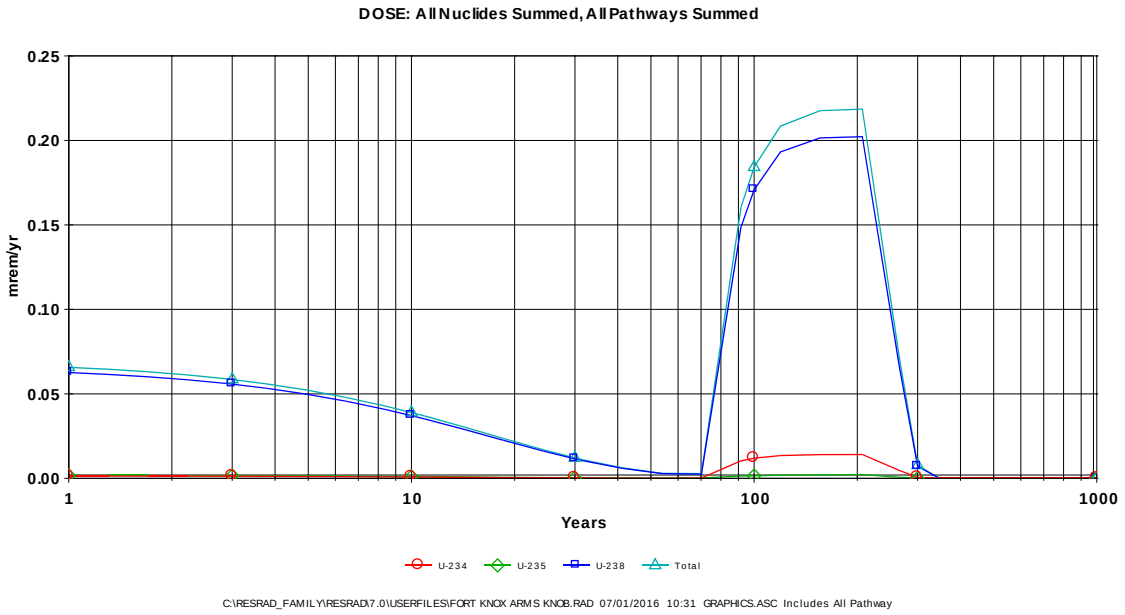


RCA Offsite (RESRAD-OFFSITE)

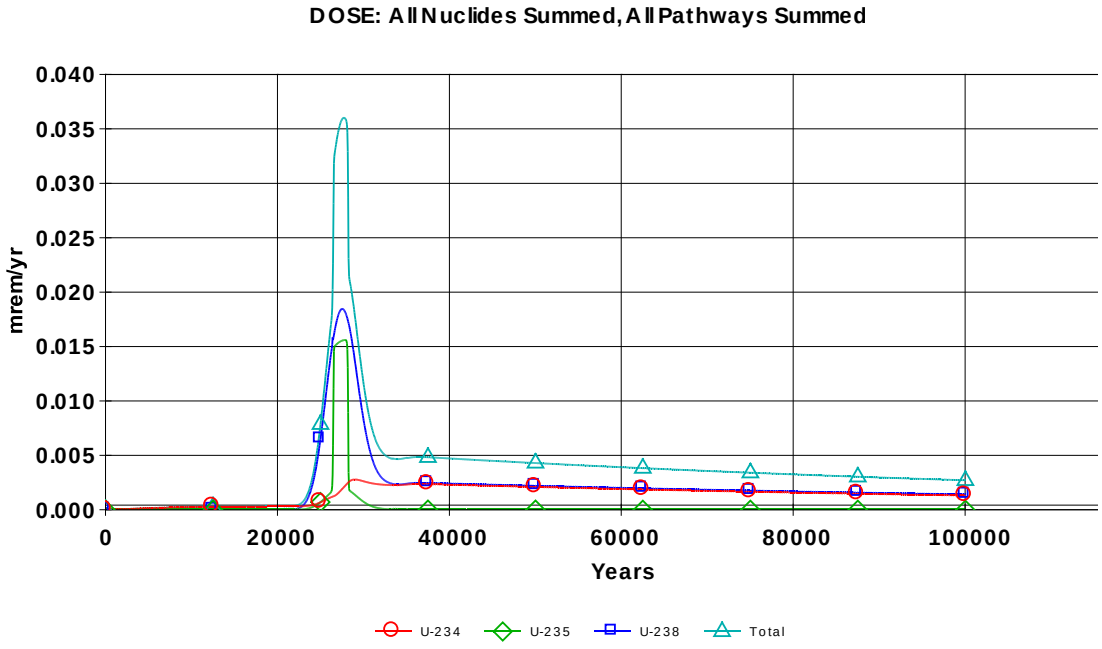


Fort Knox Arms Knob Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\ \text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\ \text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\ \text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT JOHNSON, LOUISIANA ANNEX 11

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan\
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
IUA	Intensive Use Area
kg	Kilogram
LUA	Limited Use Area
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SLUA	Special Limited Use Area
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance
WWII	World War II

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to Fort Johnson, Louisiana, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Polk, Louisiana, Annex 11 (ML21165A013) (U.S. Army 2020a) and documents the Installation name change from Fort Polk, Louisiana, to Fort Johnson, Louisiana, on June 13, 2023.

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Johnson, Louisiana. The Installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream (**SWS-04**) from the Range 33 and Range 34A RCAs, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Johnson is located in western Louisiana, approximately 3 miles southeast of the town of Leesville and approximately 35 miles southwest of the city of Alexandria in Vernon Parish, Louisiana (Figure 1-1). The installation was established in 1941 as Camp Polk and provided training for soldiers during World War II (WWII). After WW II, the installation went through a series of deactivations and reactivations revolving around international crises. Camp Polk was renamed Fort Polk in November 1955 and was activated as a permanent installation in 1961. In 1993, Fort Polk became the home of the Joint Readiness Training Center, which remains the primary tenant today. In 2023, Fort Polk was renamed Fort Johnson.

The operational range footprint at Fort Johnson includes a total of 156 ranges encompassing 150,121 acres. Ownership of the main post, as indicated by the installation boundary, is divided into two portions. In general, the northern portion of the main post is owned by the U.S. Army while the southern portion, referred to as the Intensive Use Area (IUA), is owned by the U.S. Forest Service. In addition, operational ranges are included within the Limited Use Area (LUA) and the Special Limited Use Area [SLUA], which are owned by the U.S. Forest Service (EA 2013).

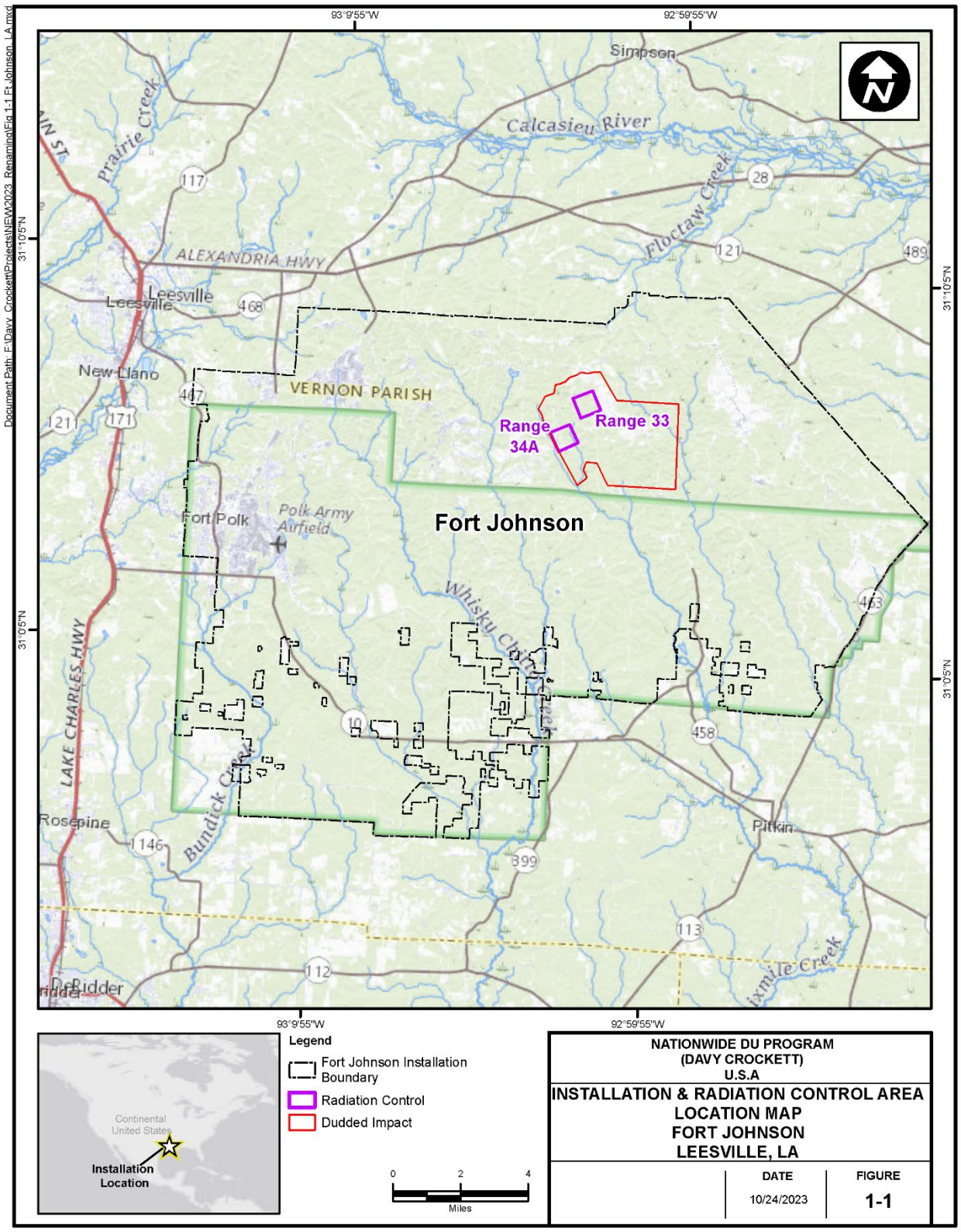

Figure 1-1. Installation and Radiation Control Area Location Map

An Archives Search Report (ASR) (USACE 2008) confirmed the presence of two ranges where the Davy Crockett weapons systems were used at Fort Johnson. Ranges 33 and 34A or the radiation control areas (RCAs) consist of 247 and 242 acres, respectively (Figure 1-2).

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies potentially may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968.

These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Ranges 33 and 34A; therefore, the U.S. Army assumes that most, if not all, of the 370 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Johnson is located on the West Gulf Coastal Plain section of the Coastal Plain Physiographic Province. The terrain is characterized by flat to gently rolling plains in the southern portion of the installation and gently rolling to rolling plains across the remainder of the installation.

The operational range area on Fort Johnson is drained by seven sub-watersheds: Anacoco Bayou, Calcasieu River, Bundick Creek, Whiskey Chitto Creek, Sixmile Creek, Tenmile Creek, and Kisatchie Bayou. The installation is located on a topographic high where nearly all streams originate on-range and flow off-installation in a radial pattern. Streams generally flow in a southerly direction and eventually empty into the Gulf of Mexico.

The Dudded Impact Area is drained to the south-southeast by West Fork Sixmile Creek and East Fork Sixmile Creek within the Sixmile Creek sub-watershed. However, only West Fork Sixmile Creek drains areas of the Dudded Impact Area associated with historical DU usage (i.e., Ranges 33 and 34A) (Figure 1-2).

Fort Johnson is underlain by three aquifers (alluvial, Chicot, and Evangeline) that are further underlain by the Castor Creek confining unit. The Chicot and Evangeline aquifers serve as a primary source of drinking water in the vicinity of the installation and the Chicot aquifer is designated as a sole-source aquifer. The depth to water in the surficial unconfined aquifers ranges from 10 to 30 feet below ground surface (bgs). Locally, groundwater flow is generally to the southeast and reflects the dip direction of the geologic units, which varies from 50 to 70 feet per mile near the outcrop and may discharge to local surface water off-range. Depth to water increases significantly down-dip. Groundwater within the Chicot aquifer is generally encountered at 30 to 40 feet bgs in supply wells located on the Cantonment Area.

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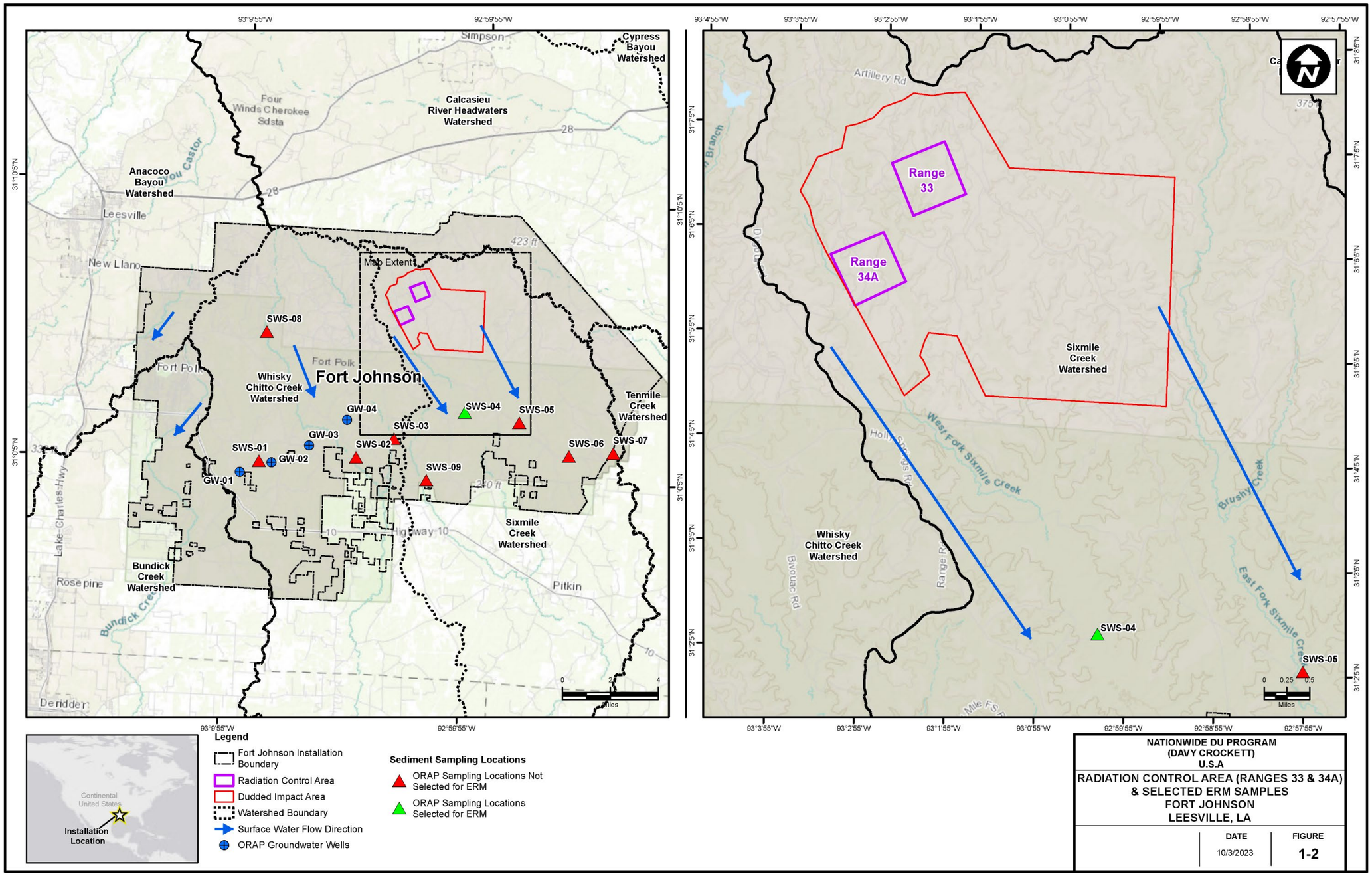

Figure 1-2. Radiation Control Area (Ranges 33 and 34A) and Selected ERM Samples

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1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the Range 33 and 34A RCAs at Fort Johnson are as follows:

- ***Surface Water Use***—No known use of surface water exists for consumption of drinking water downstream from Fort Johnson.
- ***Recreational Use***—Potential interaction with surface water and sediment is possible via recreational activities such as fishing and swimming within 15 miles downstream from the installation. During the Operational Range Assessment Program (ORAP) Phase II assessment, calculation of uranium activity ratios in surface water and sediment concluded that the detected isotopes originated from naturally occurring sources and are not attributable to DU containing munitions used at the installation (EA 2013).
- ***Sensitive Environments***—Sensitive environments downstream from Fort Johnson include riparian and wetland areas, the Kisatchie National Forest, and scenic rivers.
- ***Habitat***—The presence of wetland areas, the Kisatchie National Forest, and scenic rivers provides the potential habitat for federally and state-listed species with a full aquatic developmental life cycle (e.g., Kisatchie stream crayfish, southern creek mussel, and Louisiana pigtoe).
- ***Ecological Receptors***—The Dudded Impact Area (including the Range 33 and 34A RCAs) are drained by the West Fork Sixmile Creek, which includes off-range sensitive environments (Sixmile Creek, Kisatchie National Forest, and wetland areas) and ecological receptors, such as the Kisatchie stream crayfish, southern creek mussel, and Louisiana pigtoe.
- ***Groundwater Use***—Groundwater is used for public and private drinking water supply within 4 miles downgradient from the installation boundary. There are numerous wells downgradient from the installation's southern boundary that access water from the Chicot and Evangeline aquifers. However, the Dudded Impact Area including the RCAs does not have any downgradient well receptors within 4 miles (EA 2013).

In summary, potential human receptors include those within the Fort Johnson area and Vernon Parish relying on potential public and private water wells outside the 4-mile distance downgradient from the RCAs. Ecological receptors include sensitive environments, such as Sixmile Creek, Kisatchie National Forest, and wetland areas.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCAs or in unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCAs (Ranges 33 and 34A) at Fort Johnson are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of one sample from a location downstream from the RCAs at Fort Johnson (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling location was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-04***—The selected sampling point is located on the West Fork Sixmile Creek, downstream from Ranges 33 and 34A at the installation's southern boundary. This sample location allows for relatively easy access, and site conditions are similar to previous sampling locations at Fort Johnson. The stream channel at the SWS-04 location is approximately 20 feet wide.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the Fort Johnson RCAs based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-03 and SWS-05***—While these locations are also generally downgradient from the RCAs, neither location is part of the sub-watershed that captures surface water flow from the RCAs and discharges into the West Fork Sixmile Creek. SWS-03 is located on Birds Creek, which is part of the Whiskey Chitto Creek watershed, and SWS-05 is located on the East Fork Sixmile Creek sub-watershed.
- ***SWS-09***—This location is farther south of SWS-04 and was used as a reference sample location during the ORAP Phase II assessment as it is not influenced by runoff from the RCAs. Furthermore, as discussed above, background/reference sampling is not required under this Site-Specific ERMP.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238/uranium-234 (U-238/U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235

weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The selected downstream sampling location, SWS-04, for the environmental radiation monitoring (ERM) and the reference location, SWS-09, were sampled during the ORAP Phase II assessment in 2012 and 2013 and analyzed for uranium in surface water and sediment (EA 2013). The U-238/U-234 activity ratios from the sampling events in 2012 and 2013 is presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2012 and 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Downstream (SWS-04)	8	ND-1.42
Reference (SWS-09)	4	ND-0.87

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2012 and 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Downstream (SWS-04)	3	0.64-0.92
Reference (SWS-09)	3	0.76-1.77

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Fort Polk, Louisiana, Annex 11 (ML16265A225) (U.S. Army 2016), the Army conducted quarterly sediment sampling at the selected downstream sampling location, SWS-04, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6 in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a).The concentrations of total and isotopic uranium in sediment from the ERM sampling events at Fort Johnson are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b); Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Table 2-3 and 2-4.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Johnson.

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II quantitative assessment in 2013 were not analyzed for radiological parameters (EA 2013). Presently, no groundwater monitoring wells are located at or near the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Johnson.

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-04	6/9/2017	--- ± ---
SWS-04	8/14/2017	0.50 ± 0.51
SWS-04	12/7/2017	ND
SWS-04	3/29/2018	ND
SWS-04	6/13/2018	ND
SWS-04	9/5/2018	ND
SWS-04	12/19/2018	0.14 ± 0.18
SWS-04	2/27/2019	ND
SWS-04	6/5/2019	ND
SWS-04	9/18/2019	ND
SWS-04	11/21/2019	ND
SWS-04	2/26/2020	ND
SWS-04	4/28/2020	ND
SWS-04	8/21/2020	ND
SWS-04	11/17/2020	ND
SWS-04	3/16/2021	NC
SWS-04	10/13/2021	NC
SWS-04	3/01/2022	NC
SWS-04	11/15/2022	NC

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-04	6/9/2017	0.81 ± 0.75
SWS-04	8/14/2017	1.1 ± 0.6
SWS-04	12/7/2017	0.76 ± 0.4
SWS-04	3/29/2018	1.2 ± 0.6
SWS-04	6/13/2018	1.6 ± 1.1
SWS-04	9/5/2018	0.73 ± 0.58
SWS-04	12/19/2018	1.5 ± 1.1
SWS-04	2/27/2019	0.97 ± 0.31
SWS-04	6/5/2019	1.3 ± 0.8
SWS-04	9/18/2019	0.88 ± 0.61
SWS-04	11/21/2019	1.4 ± 0.9

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events (Continued)

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-04	2/26/2020	1.5 ± 0.8
SWS-04	4/28/2020	1.3 ± 0.7
SWS-04	8/21/2020	ND
SWS-04	11/17/2020	0.73 ± 0.25
SWS-04	3/16/2021	1.1 ± 0.5
SWS-04	10/13/2021	NC
SWS-04	3/01/2022	NC
SWS-04	11/15/2022	0.59 ± 0.48

*The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

± – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Johnson does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedure (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Johnson will be coordinated with the Fort Johnson Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample locations. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD 7.2) (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (370 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Johnson RCA

Parameter		Default Value	Fort Johnson Ranges 33 and 34A	Justification or Source
Internal Dose Library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	3.64×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	3.33×10^{-3}	
	U-238	N/A	0.55	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 10 to 30 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand (Soil is loamy fine sand from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	6.5	www.usa.com for Fort Johnson, LA
Precipitation rate (annual rainfall) (m/y)		1.0	1.5	www.usa.com for Fort Johnson, LA
Saturated Zone				
Saturated zone total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone effective porosity		0.2	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.43	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, effective porosity		0.2	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

*See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Johnson RCA

RCA Layout Parameter	Fort Johnson Ranges 33 and 34A			
Distance to nearest normally occupied area (m)	6,400			
Bearing of X axis (degrees)	0 (west)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	7500	7532
Leafy vegetables plot	500	531.25	7534	7566
Pasture, silage growing area	500	600	7716	7816
Grain fields	500	600	7566	7666
Dwelling site	500	531.25	7400	7432
Surface-water body	500	800	7816	8116
Atmospheric Transport Parameter				
Meteorological STAR file	LA_ALEXANDRIA.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	6,400			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	6,816			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	180			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Johnson does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Johnson Ranges 33 or 34A	6.4×10^{-2}	4.2×10^{-2}

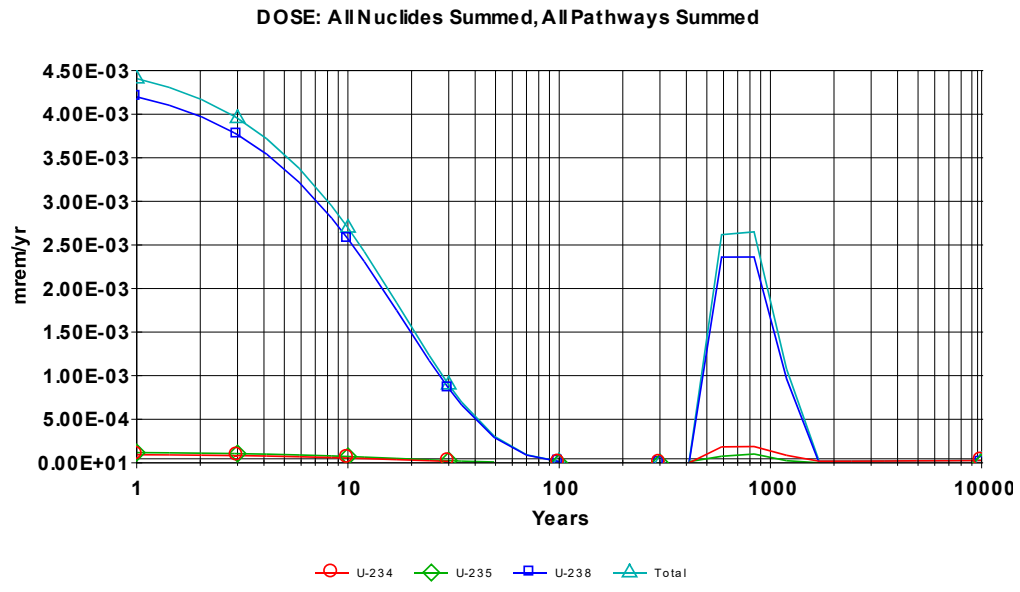
[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

Figure 4-1. Residential Farmer Receptor Dose Graphs

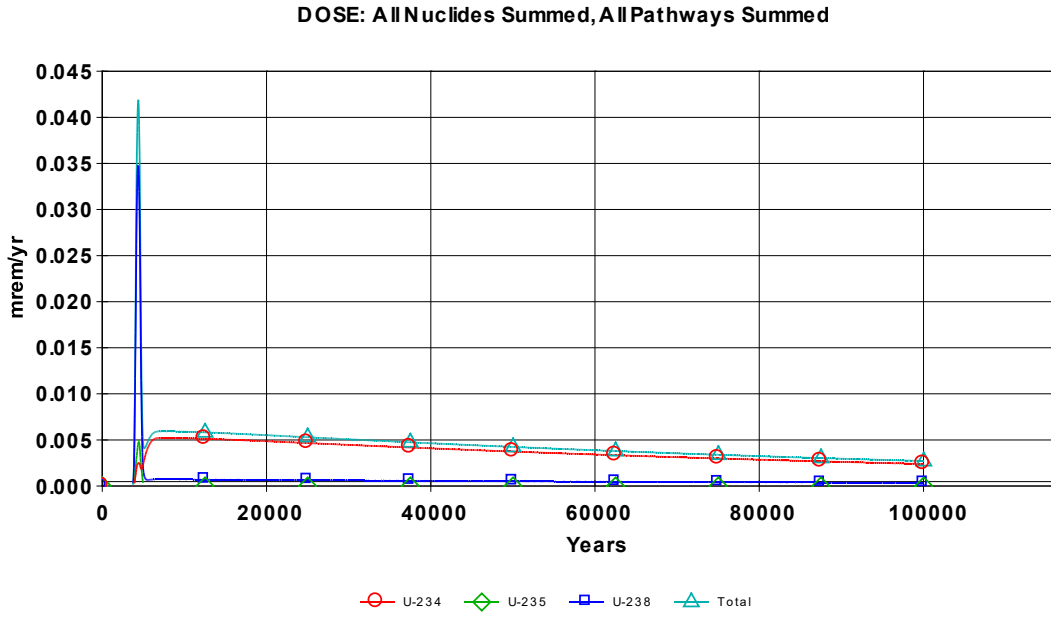
Fort Johnson Ranges 33 or 34A

RCA Onsite (RESRAD)



C:\RESRAD_FAMILY\RESRAD\7.0\USERFILES\FORT JACKSON RANGE62.RAD 08/30/2016 08:52 GRAPHICS.ASC Includes All Pathway:

RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4]	
				(Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \le D_i \le 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT RILEY, KANSAS ANNEX 12

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
gpm	Gallons per Minute
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
LRU	Lower Range of Uncertainty
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
MOUT	Military Operations in Urban Terrain
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
PAL	Project Action Level
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SDAD	Surface Danger Area Diagram
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-236	Uranium-236
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Riley, Kansas, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Riley, Kansas, Annex 12 (ML16265A226) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Riley, Kansas. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream from the Range 29 RCA (**HC-1**) and from the Range 27A and 27B RCA (**SC-1**), as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Fort Riley occupies approximately 101,732 acres in Riley, Geary, and Clay Counties, Kansas (Figure 1-1). Fort Riley provides training, readiness, and deployability for combat brigades and support for mobilization and deployment of Active Component and Reserve Component units. Training operations occur throughout the year on a daily basis at Fort Riley. Training includes field maneuvers, military operations in urban terrain (MOUT), use of combat vehicles, mortar and artillery fire, small arms fire, and aircraft flights (primarily helicopter). Fort Riley has a full infantry division composed of four brigades (Arcadis Malcom Pirnie 2013).

Fort Riley includes 92,778 acres identified as operational range areas. Fort Riley has two main Dudded Impact Areas encompassing 20,147 acres; both are located just east of the installation's center. One impact area encircles the other. There are 32 firing ranges surrounding the outer impact area. These include a demolition range, grenade ranges, gunnery ranges, mortar firing ranges, small arms ranges, and other ranges. Munitions use on the ranges includes small arms ammunition, medium- to large-caliber munitions, including high-explosive munitions and munitions with pyrotechnics and obscurants. Historical use of the range complex also included aerial rockets and bombs, and submunitions are known to have been used on about 75 percent of the central impact area. Tanks and Bradley fighting vehicles are used on the gunnery ranges.

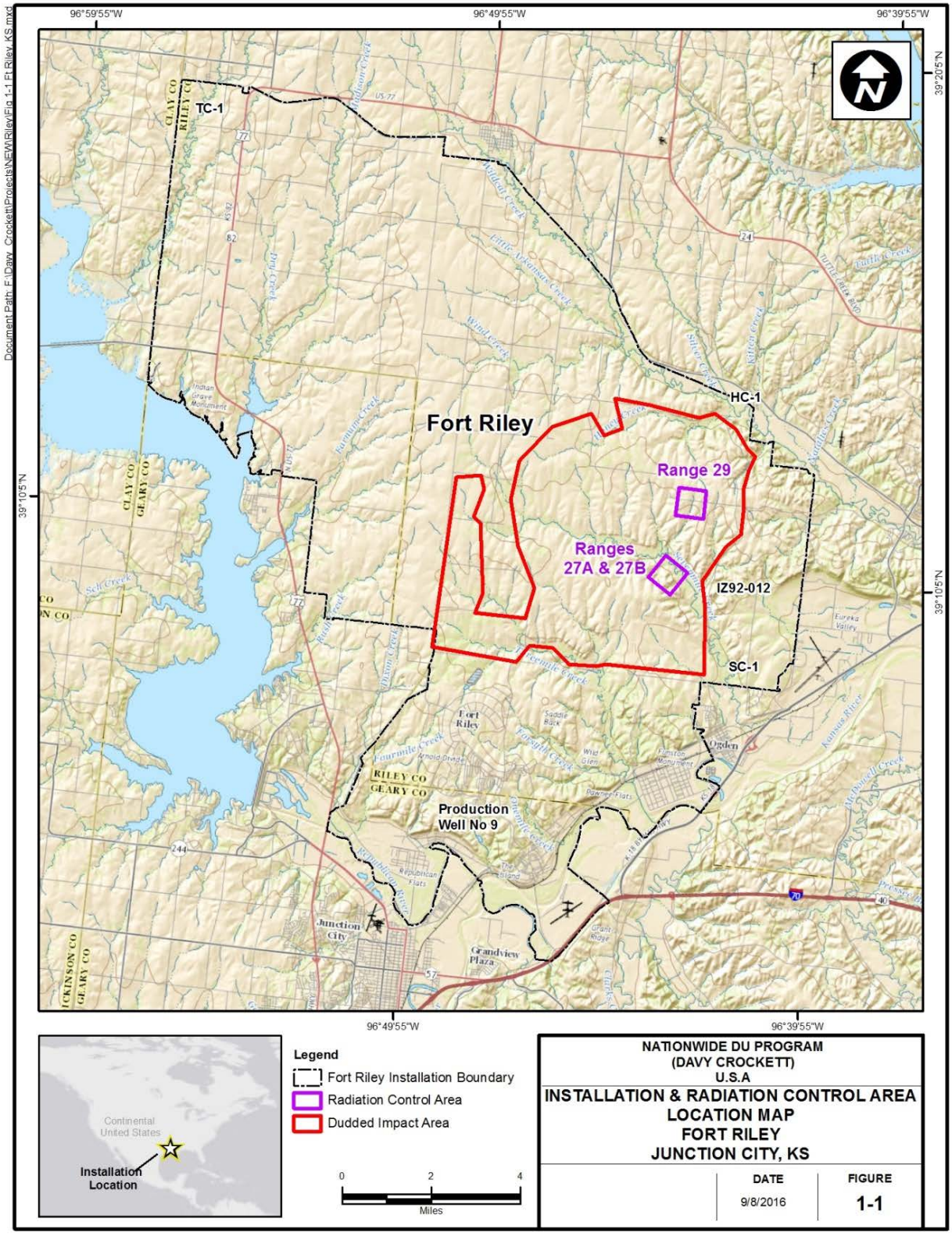

Figure 1-1. Installation and Radiation Control Area Location Map

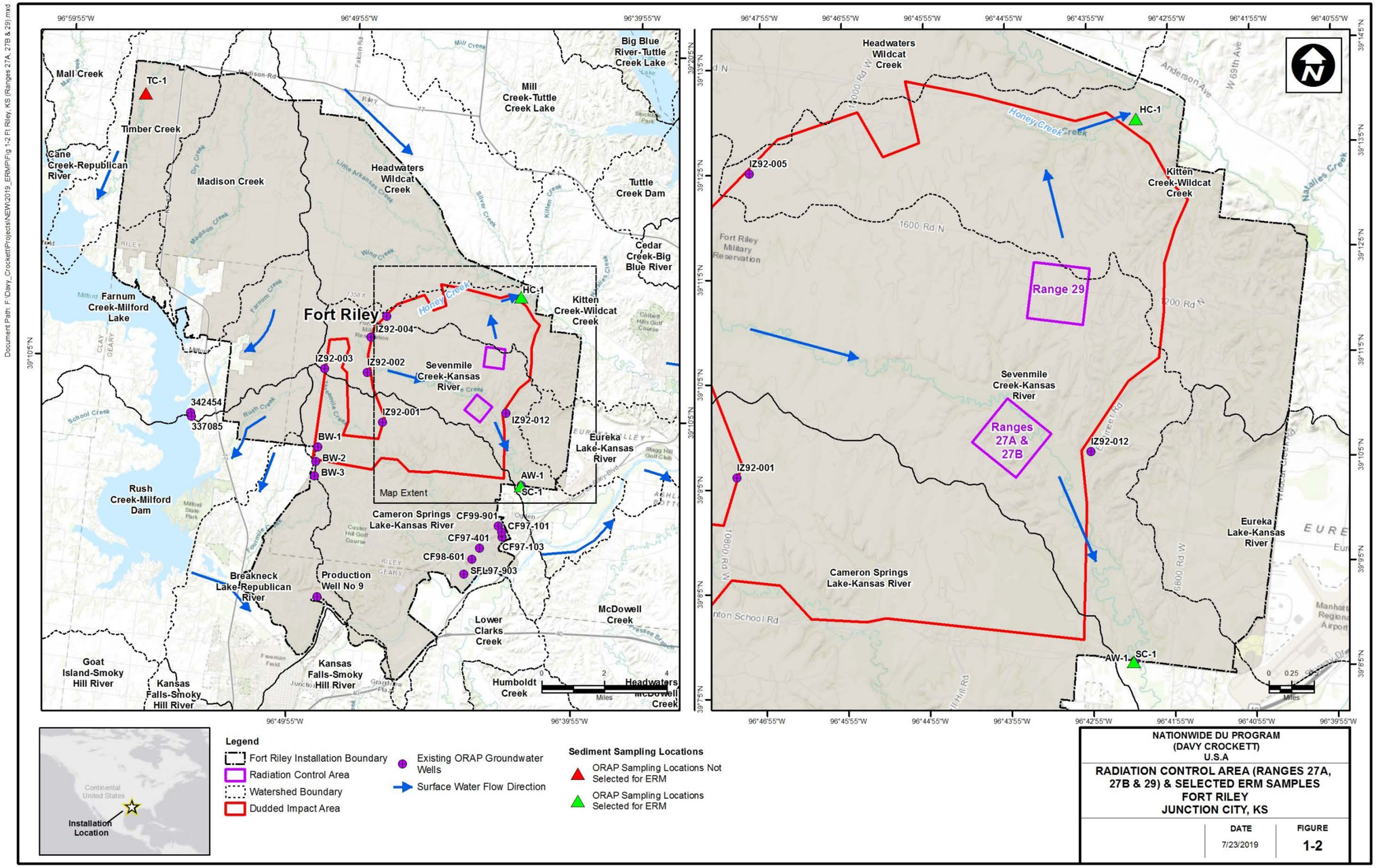

Figure 1-2. Radiation Control Area (Ranges 27A, 27B, and 29) and Selected ERM Samples

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Training and maneuver areas, which surround the Dudded Impact Areas, are used to conduct coordinated maneuvers of troops and vehicles. This training can include live-fire training using blank ammunition or live rounds fired into the designated impact areas. There are 19 large training and maneuver areas (comprising 69,333 acres), which overlap a majority of the smaller training and maneuver areas. In addition, several MOUT ranges and other training areas are located within the training and maneuver areas (Arcadis Malcom Pirnie 2013).

The Revised Final Archives Search Report (ASR) (USACE 2008) indicated that the Davy Crockett weapon system was fielded and fired at Fort Riley, Kansas. Based on the collected information, two ranges, Range 29 and the Davy Crockett Range (former Range 27B, current Range 27), were identified as used for training with the Davy Crockett weapons (Figure 1-2). Although remnants of the Davy Crockett weapon system were not found at Fort Riley during the ASR inspection, the degree of confidence in the above conclusions is high (USACE 2008). The impact areas for the historical Davy Crockett ranges or the radiation control areas (RCAs), known as Ranges 27A and 27B and Range 29, are approximately 247 acres each. The nearest normally occupied area to Ranges 27A and 27B is approximately 2.6 miles southeast of the RCA. The nearest normally occupied areas to Range 29 are approximately 4.2 miles south of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, and was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright, Joint Base Lewis-McChord (Fort Lewis and Yakima Training Area [TA]), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Fort Riley; therefore, it is assumed that most, if not all, of the 20 kilograms (kg) of DU from the rounds fired remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

The general character of the area surrounding Fort Riley is rural with small farm communities. The lands north of Fort Riley support row crop and cereal grain production. The lands to the south are predominantly rangeland. The Republican, Smokey Hill, and Kansas Rivers form part of the southern boundary of the installation. Milford Lake, a 15,000-acre impoundment of the Republican River, forms part of the installation's western boundary.

Fort Riley lies within the Flint Hills section of the Central Lowlands physiographic province. It is bordered by the Great Plains on the west and the Ozark Plateau on the east. Terrain varies from alluvial bottomlands along the Republican and Kansas Rivers on the southern portion of the installation, through the hilly to steep lands in the central and east portions, to high uplands in the northern and western portions.

Fort Riley consists of three types of topographical-physiographic area: 1) high upland prairies, 2) alluvial bottomland flood plains, and 3) broken and hilly transition zones. The high upland prairies consist of alternating layers of very gently dipping (less than 1 degree) Permian limestone and shale. The uplands often contain various shale units that cover the escarpment-forming limestones. The cutting action of streams on the thick shale units has sculpted much of the area into a rolling plateau. Two types of

alluvial bottomlands exist at Fort Riley: wide meandering floodplains of major rivers, with associated terraces; and areas created by smaller creeks and streams that cut the uplands. The transitional areas, extending from the uplands down to the valley floors are broken, sloping to steep country composed of alternating limestones and shales (U.S. Army 2007).

Fort Riley is part of the Great Plains Winter Wheat and Range Soil Resource Region. This region is covered with 1 foot or less of windblown material or loess. The loess rests upon alternating layers of weathered limestone and shale. Most soils are friable, silty loam 6 to 12 inches thick, overlying nearly impervious clays. Fort Riley's soils developed residually from parent materials and from other parent material carried by water or wind and then deposited. The permeability of the soils varies from excessively drained sandy lowland soils to tight clays with very slow permeability. Bedrock depths under those soils vary from less than 1 foot in upland areas to 40 to 60 feet in many areas of the Main Post (U.S. Army 2007).

Waters on Fort Riley are surface water in rivers, other perennial and intermittent streams, ponds and lakes, and groundwater aquifers. The Republican and Kansas Rivers form the southern boundaries of Fort Riley. With the exception of oxbow lakes, the 174 lakes and ponds on Fort Riley are constructed impoundments. Aquifers receive water through alluvial deposits of streams and rivers, porous surface deposits, and fissured limestone in uplands by means of infiltration of rain and seepage from rivers into limestone and shale.

Surface waters at Fort Riley are located within the Kansas River basin. Nearly 145 miles of rivers and streams, consisting of 14 miles of rivers and 131 miles of streams, are present on Fort Riley. All 14 streams are intermittent except for Wildcat, Sevenmile, Madison, and Timber Creeks. Streams in the southern portion of Fort Riley drain to the south to the Republican or Kansas Rivers, which form the installation's southern boundary. Streams in the western portion of Fort Riley drain toward the southwest to Milford Lake on the Republican River. Streams in the northeastern portion of Fort Riley drain to Wildcat Creek, a perennial stream that runs along the northeastern boundary of the installation. Wildcat Creek ultimately drains to the Kansas River south of Manhattan.

Sevenmile Creek is downstream from the Ranges 27A and 27B RCA and the central-southern portion of the Range 29 RCA. Sevenmile Creek is a perennial stream with a drainage basin of 17.2 square miles in the Sevenmile Creek-Kansas River watershed (Figure 1-2). Sevenmile Creek flows southeast, discharging into the Kansas River. Honey Creek is downstream from the northern portion of the Range 29 RCA. Honey Creek drains approximately 6 square miles in the northern portion of the impact area in the Kitten Creek-Wildcat Creek watershed (Figure 1-2). Honey Creek flows eastward and discharges into Wildcat Creek.

Groundwater aquifers occur in the alluvial deposits of the major streams and rivers; in the porous surface deposits; and in the fissured, near-surface limestone of the upland areas. Saturated, water-bearing sediments in the Kansas River valley range from 0 to 90 feet in thickness. Well yields of 300 to 1,000 gallons per minute (gpm) are obtained from aquifer thicknesses of 20 to 40 feet, and yields in excess of 1,000 gpm can be obtained where aquifer thicknesses exceed 40 feet.

Moderate quantities of groundwater occur in the bedrock formations of the area, in particular the Fort Riley and Florence Limestone Formations. Where these limestones are fractured and/or contain solutioned cavities, well yields of 100 gpm or more can be obtained. Wells that penetrate shales in the upland area will generally yield up to several gpm.

Discharge from the valley-fill sediments, the major water-bearing deposits, is by seepage to major streams, evapotranspiration, and withdrawal by wells. Recharge of these deposits is by direct infiltration of

precipitation, seepage from streams and ponds, return flow from irrigation, and seepage from the bedrock formations that border and underlie the valley (U.S Army 2007).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for Ranges 27A and 27B and Range 29 at Fort Riley are as follows:

- ***Surface Water Use***—In the intermediate aquifers, surface water infiltrates into the subsurface, particularly into the bedrock aquifers of the Towanda, Fort Riley, Florence, and/or Kinney Limestones, in which groundwater flows approximately west and is pumped by residential wells and wells located at Farnum Creek Campground. Groundwater samples were collected along this flow path during the Fort Riley Regional Range Study, and there were no detections of metals and/or explosives (USACHPPM 2007). However, the Regional Range Study did not include DU in the sampling event. In the alluvial aquifer, surface water runoff and/or local groundwater discharge into Sevenmile Creek (which flows off Fort Riley at the southeastern corner of the installation) recharges the Kansas River alluvial aquifer, from which groundwater is pumped by groundwater supply wells in the city of Ogden.
- ***Recreational Use***—Milford Lake, the Republican River, the Kansas River, and many other area water bodies are used for fishing and boating. Fort Riley has 29 ponds and numerous streams and rivers, which are used for recreational fishing. All state regulations for fishing are in effect on Fort Riley, dictating season and creel limits on certain species of fish, turtles, crayfish, and frogs. The Kansas, Smoky Hill, and Republican Rivers on Fort Riley's southern boundary are also used for recreational fishing. Channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*), white bass (*Morone chrysops*), striped bass (*Morone saxatilis*), hybrid white-striped bass (*Morone sp*.), walleye (*Sander vitreus*), carp (family *Cyprinidae*), freshwater drum (*Aplodinotus grunniens*), shovelnose sturgeon (*Scaphirhynchus platorynchus*), largemouth bass (*Micropterus salmoides*), and smallmouth bass (*Micropterus dolomieu*) are caught in the area's ponds, streams, and rivers. In addition, snapping and soft-shelled turtles, bullfrogs, and crayfish are taken from Fort Riley and the surrounding area and consumed.
- ***Sensitive Environments***—There is no federal threatened or endangered species critical habitat identified on Fort Riley; however, Kansas has designated critical habitat on Fort Riley for four species: piping plover (*Charadrius melodus*), least tern (*Sterna antillaru*), sturgeon chub *(Macrhybopsis gelida*), and Topeka shiner (*Notropis topeka*). In 2000, the Kansas Department of Wildlife and Parks established state-designated habitat for the Topeka shiner, to include the main stem and tributary reaches of Wildcat, Little Arkansas, and Sevenmile Creeks. As of 2004, Honey, Wildcat, Wind, Little Arkansas, and Sevenmile Creeks were state-designated critical habitat for the Topeka shiner. Wildcat Creek and Sevenmile Creeks contain sections of state-designated critical habitat for the Topeka shiner that are downstream from operational range areas. Riverine, lacustrine, and palustrine wetlands downgradient and downstream from Fort Riley operational range areas, including the Ranges 27A and 27B and Range 29 RCAs, are also considered sensitive environments.
- ***Habitat***—Habitats existing on Fort Riley may be divided into two main types: terrestrial and aquatic. Many species will use only one of these types; others will use both. Terrestrial habitats include native prairie, cool-season grassland, croplands planted as wildlife food plots or perimeter firebreaks, savanna, shelterbelts, and woodlands. Aquatic habitats include ponds, marshes, streams, reservoir coves, rivers, and sandbars. The least tern and piping plover critical habitat has been designated as all waters within the corridor along the Kansas River's

main stem. The sturgeon chub critical habitat has been designated as the Kansas River's main stem from its confluence with the Republican River and the Smoky Hill River to its confluence with the Missouri River. The Topeka shiner critical habitat has been designated as the Wildcat, Little Arkansas, and Sevenmile Creeks and their tributaries. Wetland habitats are also vital to many flora and fauna living on or in the vicinity of Fort Riley, including some state and federally listed species.

- ***Ecological Receptors***—Three federally threatened or endangered species of animals are known to occur on Fort Riley. These species are considered representative of species downstream and downgradient from Fort Riley operational range areas. The Topeka shiner resides on Fort Riley for the entire year. The least tern and the piping plover are present rarely.
- ***Groundwater Use***—Fort Riley and the surrounding communities primarily rely on groundwater from the alluvial aquifer along the Republican and Kansas Rivers for their primary source of drinking water, although some residential wells and production wells to the west of Fort Riley appear to be screened within intermediate bedrock aquifers of the Towanda, Fort Riley, Florence, and Kinney Limestone units. The surrounding communities that rely on groundwater for drinking water are Junction City to the south of the installation (population 20,000), Riley to the north (population 800), Grandview Plaza to the south (population less than 1,000), and Ogden to the southeast (population 1,600). The city of Manhattan (population 38,000) is about 7 miles northeast of southern Fort Riley along the Kansas River and obtains at least some of its water supply from the Kansas River alluvial aquifer. In addition, rural water districts within Riley and Geary Counties obtain their drinking water supply from the alluvial aquifer in the Kansas River Valley. Groundwater is also used for crop irrigation in the river valleys. Irrigation water use occurs mainly during the summer months. Fort Riley obtains its drinking water primarily from groundwater wells that are screened in the alluvial deposits. The Fort Riley Main Post wells consist of eight wells located in alluvial deposits of the Republican River approximately 1 mile upstream from its confluence with the Smoky Hill River. Water levels in these water supply wells range from 15 to 25 feet below ground surface (bgs). There are groundwater wells used for domestic water supply that are located downgradient from Fort Riley within the 4-mile area (Malcolm Pirnie 2010).

Potential human receptors include recreational users of surface water bodies for fishing and swimming and those relying on potential public and private wells within 4 miles downgradient from Fort Riley for potable water. Ecological receptors include sensitive environments (e.g., Topeka shiner).

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCAs (Ranges 27A and 27B and Range 29) at Fort Riley are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the collection of samples from two locations downstream from the Ranges 27A and 27B and Range 29 RCAs (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling locations at Ranges 27A and 27B and Range 29 were selected based on the surface water hydrology and potential for DU contribution and are located as follows:

- ***SC-1***—The selected sampling point is located on Sevenmile Creek, downstream from the Ranges 27A and 27B RCA and the southern portion of the Range 29 RCA. Sevenmile Creek is a perennial stream with a drainage basin of 17.2 square miles. Sevenmile Creek flows southeast, discharging into the Kansas River. The sampling location SC-1 is located upstream of the Kansas River and at the installation boundary.
- ***HC-1***—The selected sampling point is located on Honey Creek, downstream from the northern portion of the Range 29 RCA. Honey Creek drains approximately 6 square miles in the northern portion of the impact area and drains numerous small arms firing ranges north of the impact area. Honey Creek flows eastward and discharges into Wildcat Creek. The sampling location HC-1 was located immediately upstream of the confluence with Wildcat Creek and within the installation boundary.

The proposed surface water and sediment sampling at SC-1 and HC-1 is focused on Sevenmile Creek-Kansas River and Kitten Creek-Wildcat Creek watersheds because they are downstream from the RCAs. TC-1 (Timer Creek) is a reference location that was sampled during the Operational Range Assessment Program (ORAP) and is not downstream from the RCAs.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238) /uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect an additional surface water and sediment sample within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to

determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

Surface water at the selected downstream sampling locations, HC-1 and SC-1, for the ERM and upstream reference location were sampled during the ORAP Phase II assessment in April and June 2010 (Arcadis Malcolm Pirnie 2013). The results of the April and June 2010 sampling events are presented in Table 2-1.

Table 2-1. Uranium Surface Water Analytical Results Collected During the 2010 ORAP Phase II Assessment

Sample Location	Number of Samples	Range of Concentrations (µg/L)
HC-1	2	1.52-2.44
HC-1 (dissolved)	2	1.46-2.36
SC-1	2	0.971-2.37
SC-1 (dissolved)	2	0.481-2.54
TC-1	2	2.56-3.36
TC-1 (dissolved)	2	2.54-3.28

In accordance with the Site-Specific ERMP for Fort Riley, Kansas, Annex 12 (ML16265A226) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, HC-1 and SC-1, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the environmental radiation monitoring (ERM) sampling events at Fort Riley are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-2 and 2-3.

Table 2-2. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
HC-1	5/22/2017	0.79 +/- 0.2
SC-1	5/22/2017	0.91 +/- 0.23
HC-1	9/12/2017	0.79 +/- 0.27
SC-1	9/12/2017	0.70 +/- 0.24
HC-1	11/21/2017	0.64 +/- 0.22
SC-1	11/21/2017	0.53 +/- 0.12
HC-1	3/13/2018	--- +/- ---
SC-1	3/13/2018	0.99 +/- 0.21
HC-1	5/22/2018	--- +/- ---
SC-1	5/22/2018	0.80 +/- 0.35
HC-1	9/6/2018	0.73 +/- 0.33
SC-1	9/6/2018	0.92 +/- 0.29
HC-1	11/27/2018	--- +/- ---
SC-1	11/27/2018	0.67 +/- 0.14

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

--- +/--- – Indicates surface water sample was not collected because water was not present during sampling.

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
HC-1	5/22/2017	0.70 +/- 0.26
SC-1	5/22/2017	0.80 +/- 0.3
HC-1	9/12/2017	1.0 +/- 0.3
SC-1	9/12/2017	1.0 +/- 0.3
HC-1	11/21/2017	1.0 +/- 0.2
SC-1	11/21/2017	1.0 +/- 0.2
HC-1	3/13/2018	1.0 +/- 0.3
SC-1*	3/13/2018	1.1 +/- 0.2
HC-1	5/22/2018	1.2 +/- 0.4
SC-1*	5/22/2018	1.0 +/- 0.2
HC-1	9/6/2018	1.5 +/- 0.4
SC-1*	9/6/2018	1.2 +/- 0.2
HC-1	11/27/2018	--- +/- ---
SC-1	11/27/2018	0.98 +/- 0.19

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-3, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Riley.

2.2 GROUNDWATER

Twenty-six groundwater samples were collected and analyzed for uranium (all 26 were analyzed for total and isotopic uranium and 12 of the 26 samples were analyzed for dissolved uranium) during the ORAP Phase II assessment in May 2010 (Arcadis Malcom Pirnie 2013). The results of the May 2010 sampling event are presented in Table 2-4. The existing groundwater monitoring wells are shown in Figure 1-2.

Total uranium was detected in 25 of 26 groundwater samples collected during the ORAP Phase II assessment. None of the samples contained total uranium at a concentration that exceeded the project action levels (PALs); however, groundwater samples GWSE-BW2-GW-01 and GWSE-CFW-GW-03 had concentrations that were greater than the lower range of uncertainty (LRU). The remaining detected concentrations of total uranium were generally two orders of magnitude less than the PAL and one order of magnitude less than the LRU. Dissolved uranium was detected in all 12 groundwater samples analyzed.

Total uranium concentrations in groundwater may be due to both naturally occurring sources and range-related sources; therefore, the groundwater samples also were analyzed for isotopic uranium (U-234, U-235/uranium-236 [U-236], U-238) to determine if the total uranium was due to naturally occurring sources, range-related sources, or a combination of the two sources. U-234 and U-238 typically have equivalent radio activities in naturally occurring uranium (e.g., both U-234 and U-238 account for approximately 48.9 percent of the radioactivity), but U-238 is elevated relative to U-234 in DU (USEPA 2006). The isotopic uranium results indicate that the U-234 radioactivity is greater than the U-238 radioactivity for both of the groundwater samples that had total uranium concentrations greater than the LRU. Because the results indicate that U-238 radioactivity is less than U-234, the total uranium detected in the groundwater samples appears to be due to naturally occurring sources and does not have a range-related source (Arcadis Malcom Pirnie 2013).

Table 2-4. Uranium Groundwater Analytical Results (Detections Only) Collected During the 2010 ORAP Phase II Assessment

Sample Location (Depth)	Result (µg/L)
AW-1 (18-20')	Total 4.79 / Dissolved 4.6
AW-1 (28-30')	Total 5.33 / Dissolved 3.72
BW-1 (75-85')	Total 1.61 / Dissolved 1.38
BW-1 (103-113')	Total 1.56 / Dissolved 1.1
BW-1 (160-170')	Total 7 / Dissolved 1.57
BW-2 (85-95')	Total 4.71 J / Dissolved 2.48 J
BW-2 (155-165')	Total 1.64 J / Dissolved 1.52 J
BW-2 (172-182')	Total 4.71 / Dissolved 2.78
BW-2 (220-230')	Total 20.3 J / Dissolved 2.63 J
BW-3 (85-95')	Total 1.34 / Dissolved 1.27
BW-3 (170-180')	Total 1.94 / Dissolved 1.67
BW-3 (130-140')	Total 1.76 J / Dissolved 1.19 J
CF98-601 (19-29')	Total 4.23 J
CF97-103 (59-69')	Total 4.26 J
CF97-101 (13.5 - 23.5')	Total 20 J
CF97-401 (16.20-26.20')	Total 1.56 J
SFL97-903 (43.80-53.80')	Total 3.41 J
337085 (110-130')	Total 3.55 J
CF99-901 (13.05-23.05')	Total 5.73 J
GW Prod Well #9 (N/A)	Total 6.63 J
IZ92-001 (50-60')	Total 4.62 J
IZ92-002 (52-62')	Total 1 J
IZ92-003 (123-143')	Total 1.01
IZ92-012 (35-45')	Total 2.2 J

J: The analyte was positively identified; however, the result should be considered an estimated value.

Presently, no groundwater monitoring wells are located at or near the RCA. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Riley.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, RCAs for Ranges 27A and 27B and Range 29 do not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Riley will be coordinated with the Fort Riley Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to establish the weight percent U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of depleted uranium listed on the license for the installation (20 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Riley RCAs

Parameter		Default Value	Ranges 27A and 27B	Range 29	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone					
Soil concentrations (pCi/g)	U-234	N/A	1.97×10^{-3}	1.97×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity*/ (CZ area × CZ depth × CZ density)
	U-235	N/A	1.8×10^{-4}	1.8×10^{-4}	
	U-238	N/A	0.03	0.03	
Area of contaminated zone (m^2)		10,000	1,000,000	1,000,000	
Depth of contaminated zone (m)		2	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	Phase I Periodic Review document (U.S. Army 2014) indicates depth to groundwater is 10 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt (Soil is Silty Loam for Ranges 27A and 27B; soil is Silty Clay Loam for Range 29; determined from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	227	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam or Silty Clay Loam
Contaminated zone b parameter		5.3	5.3	7.75	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam or Silty Clay Loam
Average annual wind speed (m/s)		2.0	7.7	7.7	**www.usa.com** for Fort Riley, KS
Precipitation rate (annual rainfall) (m/y)		1.0	0.8	0.8	**www.usa.com** for Fort Riley, KS
Saturated Zone					
Saturated zone total porosity		0.4	0.45	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone effective porosity		0.2	0.20	0.20	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	227	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam or Silty Clay Loam
Saturated zone b parameter		5.3	5.3	7.75	RESRAD Manual (DOE 2001) Table E.2 for Silty Loam or Silty Clay Loam
Unsaturated Zone					
Unsaturated zone 1, total porosity		0.4	0.45	0.45	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, effective porosity		0.2	0.20	0.20	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	5.3	7.75	RESRAD Manual (DOE 2001) Table E.2 for Silty Loam or Silty Clay Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	227	53.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam or Silty Clay Loam

* See Table 1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Riley RCAs

RCA Layout Parameter	Ranges 27A and 27B				Range 29			
Distance to nearest normally occupied area (m)	3,800				2,500			
Bearing of X axis (degrees)	180(east)				135(northeast)			
X dimension of Primary Contamination (m)	1,000				1,000			
Y dimension of Primary Contamination (m)	1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	4900	4932	500	531.25	3600	3632
Leafy vegetables plot	500	531.25	4934	4966	500	531.25	3634	3666
Pasture, silage growing area	500	600	5116	5216	500	600	3816	3916
Grain fields	500	600	4966	5066	500	600	3666	3766
Dwelling site	500	531.25	4800	4832	500	531.25	3500	3532
Surface-water body	500	800	5216	5516	500	800	3916	4216
Primary Contamination Parameter								
Length parallel to aquifer flow*	1000				255			
Atmospheric Transport Parameter								
Meteorological STAR file	KS_TOPEKA.str				KS_TOPEKA.str			
Groundwater Transport Parameter								
Distance to well (parallel to aquifer flow) (m)	3800				2500			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	4216				2916			
Distance to well (perpendicular to aquifer flow) (m)	0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	0				315			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Riley does not exceed 1.0 × 10-2 milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Riley Ranges 27A and 27B	3.5×10^{-3}	1.2×10^{-3}
Fort Riley Range 29	3.5×10^{-3}	1.2×10^{-3}

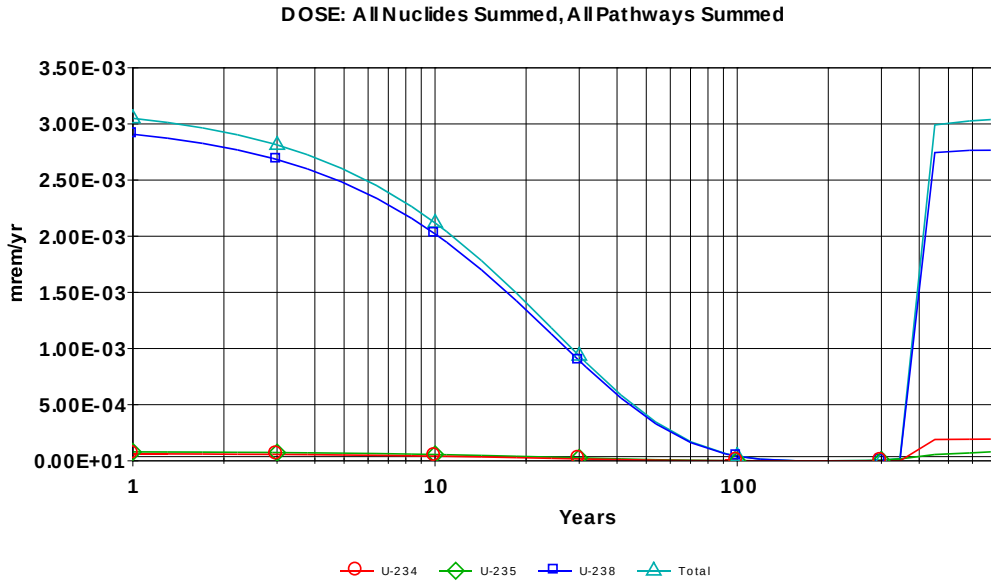
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

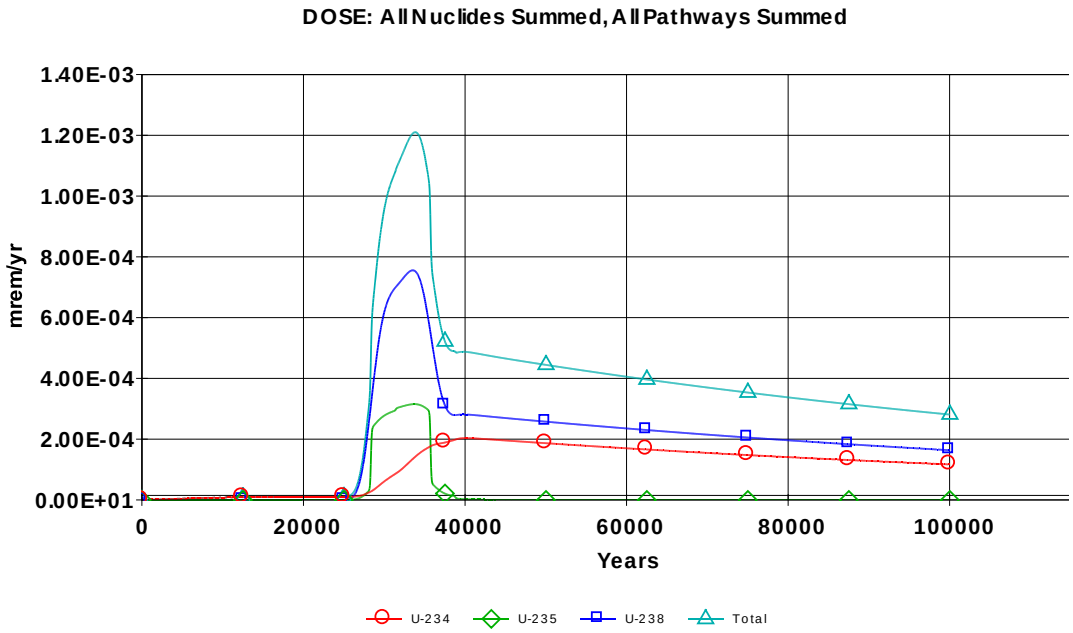
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Riley Ranges 27A and 27B

RCA Onsite (RESRAD)

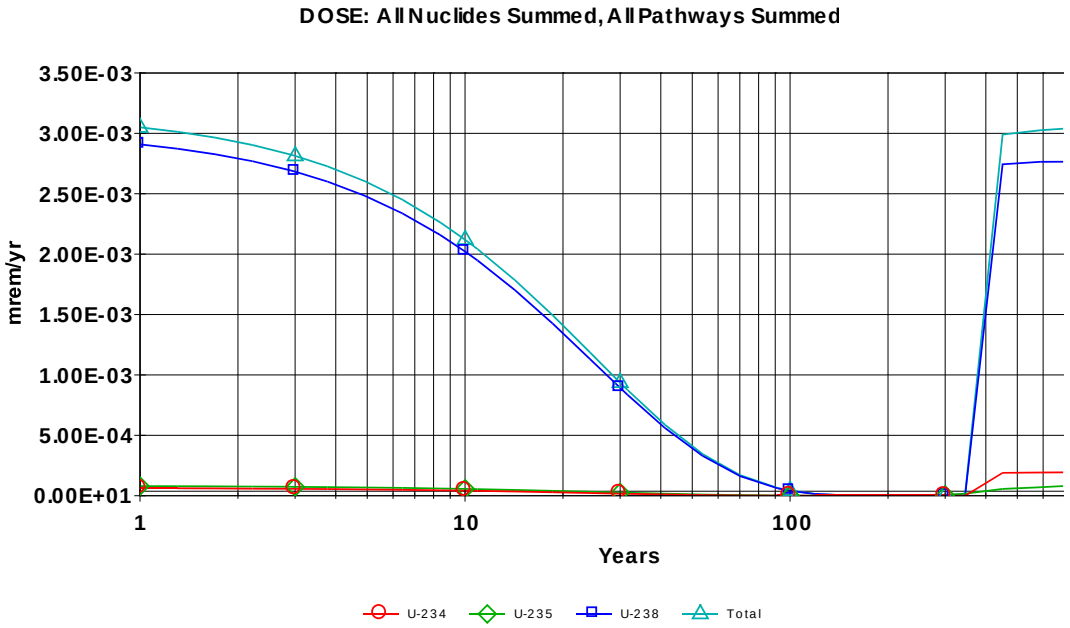


RCA Offsite (RESRAD-OFFSITE)

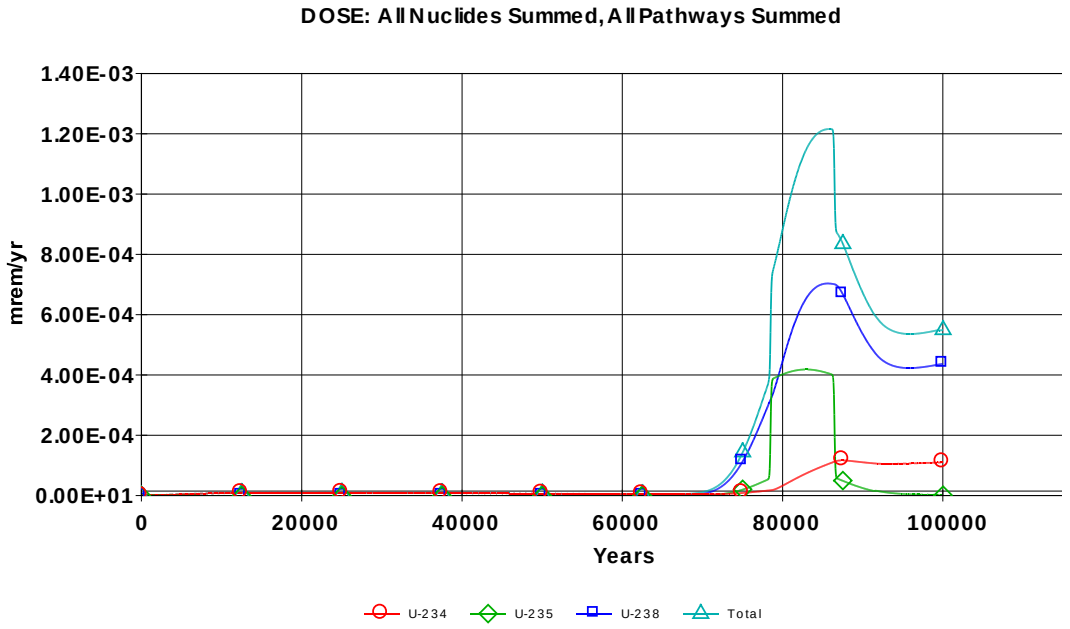


Fort Riley Range 29

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



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Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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REVISED FINAL

SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT SILL, OKLAHOMA ANNEX 13

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
SWMU	Solid Waste Management Unit
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
USGS	U.S. Geological Survey
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Sill, in Lawton, Oklahoma, in addition to those presented in the Programmatic Approach for the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Fort Sill, Oklahoma, Annex 13 (ML16265A227) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Sill. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream (**SWS-06A**) from the FP 182/West Range RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Fort Sill is a 93,829-acre installation located in Comanche County, Oklahoma, 90 miles southwest of Oklahoma City (Figure 1-1). The installation is bound on the north by Wichita Mountains National Wildlife Refuge and the town of Medicine Park. Fort Sill is bordered to the south by the towns of Indiahoma and Cache and the city of Lawton. The installation boundaries extend approximately 26 miles from east to west and approximately 6 miles from north to south. Fort Sill lies within the Central Lowlands Province and is generally characterized as a region of rolling topography and moderate relief.

In 1869, Fort Sill was originally staked out by Major General Philip H. Sheridan, who led a campaign into Indian Territory to stop hostile tribes from raiding border settlements in Texas and Kansas. The last Indian lands in Oklahoma opened for settlement in 1901, and 29,000 homesteaders registered for the land lottery at Fort Sill. The frontier disappeared, and the mission of Fort Sill gradually changed from cavalry to field artillery. In 1902, the first artillery battery arrived at Fort Sill, and the last cavalry regiment departed in 1907. Historically, various training activities at Fort Sill included the Infantry School of Musketry, the School for Aerial Observers, the Air Service Flying School, and the Army Aviation School. In 1911, the School of Fire for the Field Artillery was founded at Fort Sill, where it continues to operate today as the renowned U.S. Army Fires School of Excellence.

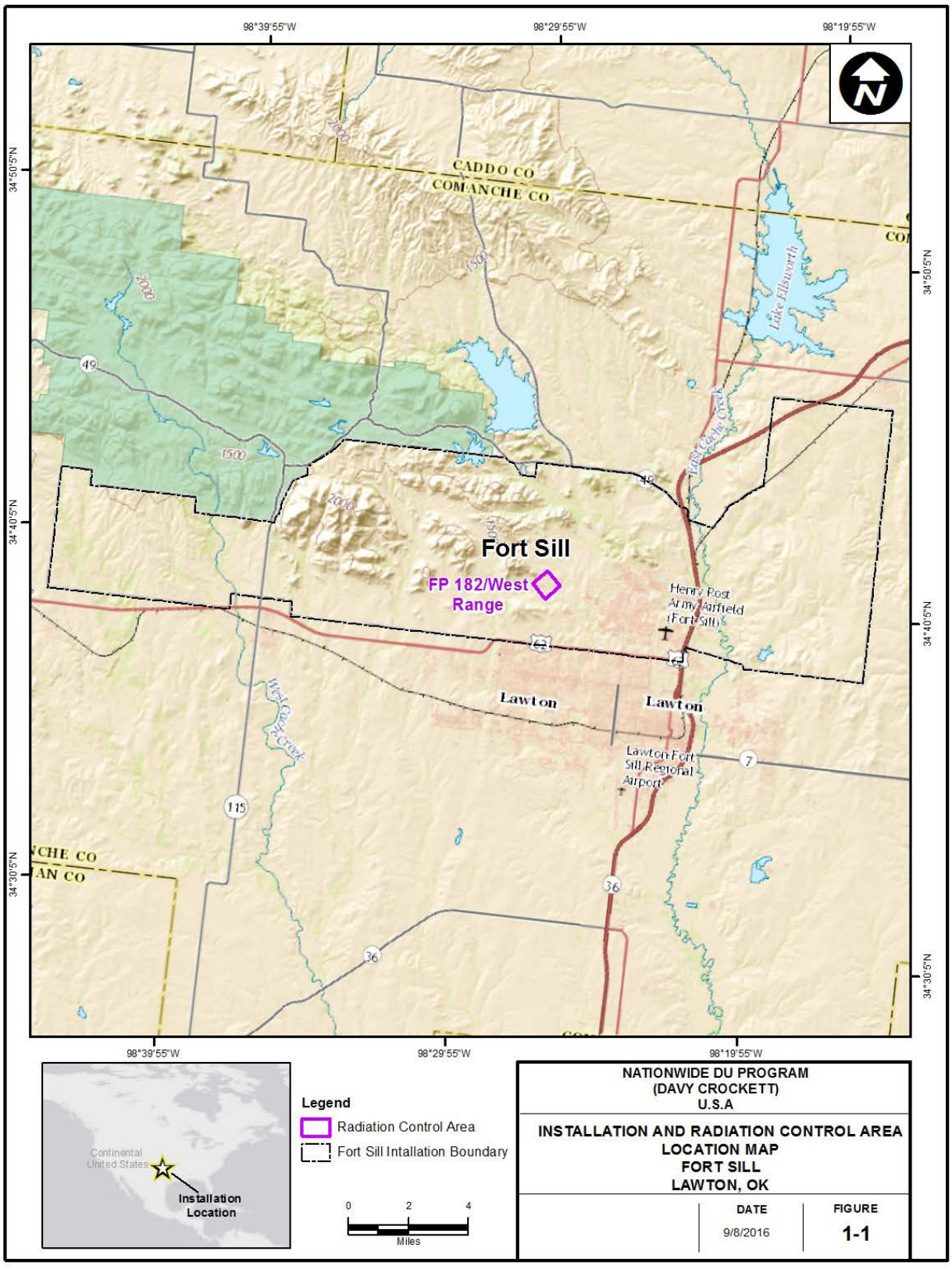

Figure 1-1. Installation and Radiation Control Area Location Map

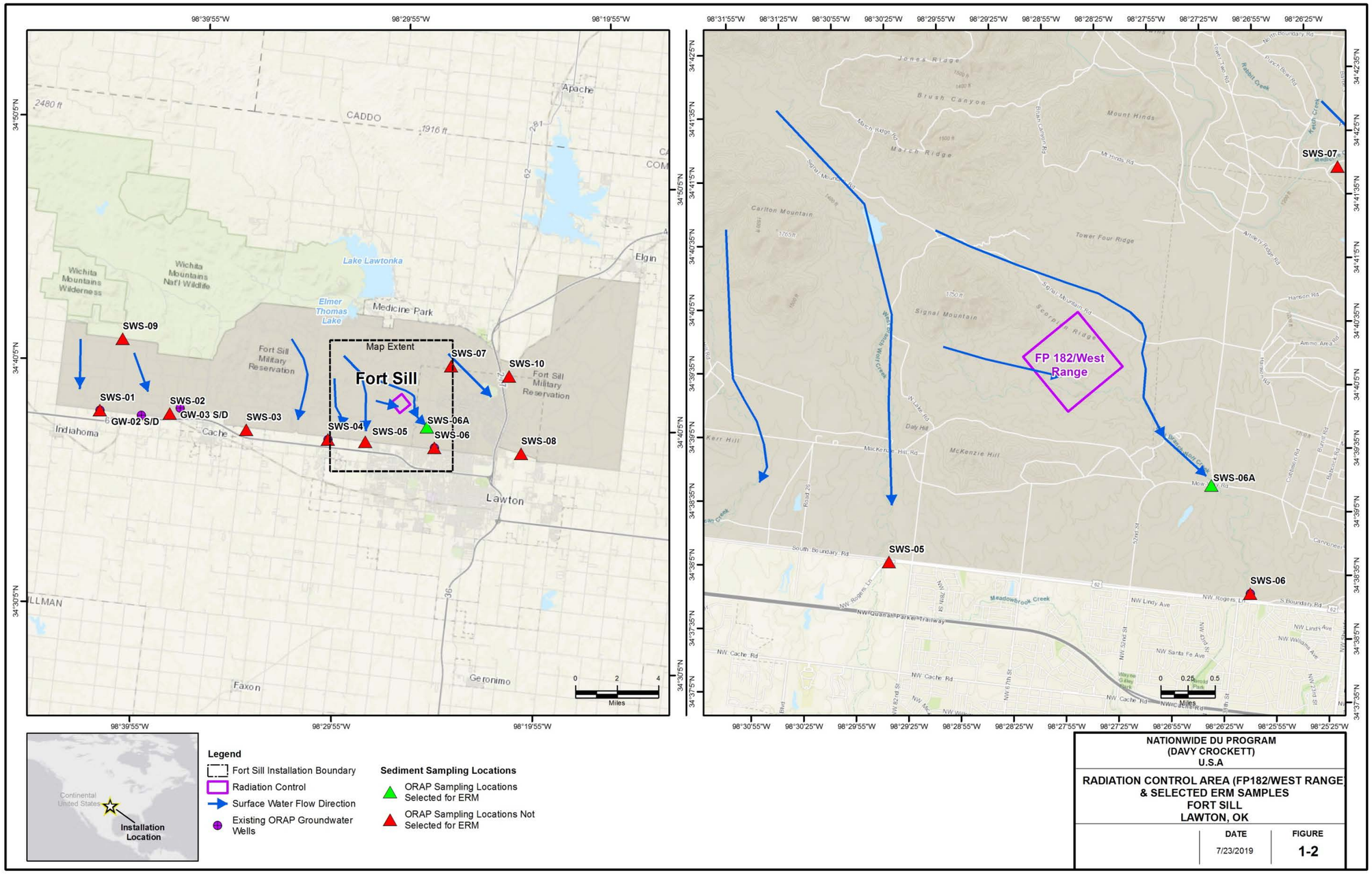

Figure 1-2. Radiation Control Area (FP 182/West Range) and Selected ERM Samples

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Currently, Fort Sill operates as the U.S. Army Field Artillery Center with the mission of training field artillery leaders, supporting unit training and readiness, and deploying operating forces. The installation mission is accomplished by the comprehensive use of 231 ranges located throughout the operational area footprint, including 4 major impact areas: the North and South Arbuckle Ranges, the West Range, and the Quanah Range, each surrounded by multiple firing points and training areas. Only the Cantonment Area, located adjacent to the city of Lawton in the south-central portion of the base, and the two smaller non-operational use areas, located centrally between the North and South Arbuckle Range Impact Areas, are excluded from training activities. The nearest normally occupied areas to the radiation control area (RCA) is a movie theater, which is located approximately 2.5 miles south of the RCA (Figure 1-2). The RCA is located in the West Range, more specifically at training range FP 182/West Range.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the RCA; therefore, it is assumed that most, if not all, of the 120 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Fort Sill is located in the Osage Plains section of the Central Lowland Province of Oklahoma and can be divided into three distinct landforms: low plains, high plains, and low hills.

Surface water drainage across Fort Sill is divided into three watersheds with boundaries generally from north-to-south and containing both intermittent and perennial creeks. Approximately 90 percent of the land area is within the West Cache and East Cache Creek watersheds, while the remaining 10 percent is within the Beaver Creek watershed to the east. The RCA is located within the East Cache Creek watershed.

Many of the surface water systems within the East Cache Creek watershed originate north of the installation and exit the installation's southern boundary through one perennial creek (East Cache Creek) and a number of intermittent creeks. Intermittent West Cache Creek was noted to have sustained flow during the U.S. Army Operational Range Assessment Program (ORAP) Phase I assessment (EA 2014). These creeks are sourced by Elmer Thomas Lake, Lake Lawtonka, and Lake Ellsworth to the north, which capture runoff from the Wichita Mountains. Based upon a review of precipitation patterns and stream flow data from U.S. Geological Survey (USGS) gauging stations on Little Beaver Creek (25 miles southeast of Fort Sill) and Jimmy Creek (20 miles northwest of Fort Sill), the highest stream flows (wet season) typically occur from May to June.

The nearest known domestic or public supply well is approximately 4.5 miles downgradient from the RCA. Domestic or public supply wells are screened within one of three aquifers. Since the three aquifers recharge from youngest to oldest, and since all of the potential receptor wells are also screened within one of these aquifers, it is unnecessary to describe additional aquifers within this report. The groundwater flow

is to the southeast (EA 2014). The Quaternary alluvium, Permian Post Oak Conglomerate, and Cambro-Ordovician Arbuckle-Timbered Hills aquifers are described below:

- ***Quaternary Alluvium—***The Quaternary alluvium is the least prevalent member of the Fort Sill groundwater system and is present along most of the major surface water pathways with an increased prevalence along the southern third of Fort Sill. The alluvium consists of sand, clay, and gravel, and is recharged by stream flow and/or precipitation on the floodplain.
- ***Permian Post Oak Conglomerate—***The Permian Post Oak Conglomerate aquifer occurs along the flanks of the igneous rocks of the Wichita Mountains and overlies the Arbuckle-Timbered Hills aquifer. This aquifer comprises a combination of cobbles, gravel, sand, silt, clay, shale, and limestone conglomerate. Recharge occurs through direct infiltration via precipitation and indirect recharge through overlying alluvium, which includes runoff from the low-permeability Cambrian volcanic complexes comprising the Wichita Mountains. The thickness of the Post Oak Conglomerate is approximately 300 feet below ground surface (bgs) at the installation boundary and thickens to the south. Outcrops of the Quaternary alluvium occur as thin and localized units within the stream valleys.
- ***Cambro-Ordovician Arbuckle-Timbered Hills Aquifer—***The Cambro-Ordovician Arbuckle-Timbered Hills comprises mainly dolomite with interbedded shale, outcrops only in two small sections of Fort Sill: near the south-central boundary and a small area along the northern boundary of the installation. The total thickness of the aquifer can range from several feet to upwards of 6,000 feet well southeast of Fort Sill. Aquifer recharge within the installation occurs primarily though the Post Oak Conglomerate on the southern flank of the Wichita Mountains. Aquifer depth, according to available well information, is between 700 and 1,020 feet. Due to the depth to water averaging approximately 140 feet bgs, it is likely that an upward gradient exists within this aquifer.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCA at Fort Sill are as follows:

- ***Surface Water Use***—Surface water migrating downstream from Fort Sill within the East Cache Creek watershed and associated tributaries contains ecological receptors, including sensitive wetlands. Surface water comprises a portion of the drinking water for Fort Sill and the town of Lawton, Oklahoma to the south; however, the surface water is captured upstream of the installation.
- ***Recreational Use—***A potential for recreational fishing downstream from Fort Sill exists.
- ***Sensitive Environments***—Sensitive environments (i.e., wetlands) are found within the non-operational areas of Fort Sill. Additional wetlands are identified downstream from Fort Sill along each of the tributaries exiting the installation to the south.
- ***Habitat***—Primary habitat types at Fort Sill include forested areas and scrubland or grassland areas. The installation is located within a transition zone of eastern tall grass prairie and southwestern short grass prairies, which comprise the dominant habitat. Habitat for Federal- and/or state-listed threatened and endangered species (black capped vireo (*[Vireo atricapilla]*) is found on in the northern portions of the West and Quanah Ranges of Fort Sill; however, the habitat is not found in the RCA.

- ***Ecological Receptors***—The National Wetlands Inventory identified sensitive environments (i.e., wetlands) within 1 mile downstream from the installation boundary within the East Cache Creek watershed.
- ***Groundwater Use***—No wells currently exist on Fort Sill. Most historical wells installed on the installation were monitoring wells surrounding solid waste management units (SWMUs). The unconfirmed location of a local supply well was noted during the ORAP Phase II assessment; however, the location of this well is unknown and is presumed to be abandoned. Production wells and private landowner supply wells are used for potable water downgradient from Fort Sill. The nearest of these wells to the RCA is approximately 4.5 miles downgradient from the RCA; therefore, consumers of waters from these wells are considered potential receptors. Production wells and private landowner supply wells are screened within either the Cambro-Ordovician Arbuckle-Timbered Hills or Permian Post Oak Conglomerate aquifers and may receive recharge via percolation of precipitation from surface areas, including the RCA.

Potential human receptors include those to the southeast of the RCA beyond the installation boundary that rely on private wells or potential public wells for potable water. Ecological receptors include sensitive environments to the south of the RCA receiving surface water (e.g., wetlands).

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCA at Fort Sill are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of a sample from a location downstream from the RCA (Figure 1-2) in an intermittent creek near the Fort Sill installation boundary. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling location at Fort Sill was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***SWS-06A***—The selected sampling point is located on the East Branch of Wolf Creek downgradient from flow from the part of the West Range where the RCA is located.

Additional locations were sampled during the ORAP Phase II assessment (Figure 1-2). These locations were not selected for evaluation of the FP 182/West Range RCA based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-01, SWS-02, SWS-03, SWS-04, SWS-09, SWS-09A***—These sampling points are located in the West Cache Creek watershed. These sampling points are not relevant because the RCA is not within their watershed.
- ***SWS-05***—This sampling point is located where the West Branch of Wolf Creek exits the installation. This sampling point is not relevant because the RCA is not within its watershed.
- ***SWS-06***—This sampling point is downstream from SWS-06A where the East Branch of Wolf Creek exits the installation. SWS-06 is located farther downstream and sustains lower flows than SWS-06A.
- ***SWS-07, SWS-08, SWS-10***—These sampling points are located to the north and east of the RCA in a portion of the East Cache Creek watershed that is upstream where the East Branch of Wolf Creek enters the East Cache Creek. These sampling points are not relevant because the RCA is not within their watershed.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U 234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy

(ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

Sediment was collected at the recommended environmental radiation monitoring (ERM) sampling point, SWS-06A, the downstream sampling point, SWS-06, and the upstream reference sampling point, SWS-09 during the ORAP Phase II assessment in 2012 and analyzed the samples for uranium (EA 2014). Surface water was not available at these sampling points, so additional sediment sampling was performed. The range of U-238/U-234 activity ratios from the May, June, and September 2012 sampling events is presented in Table 2-1.

Table 2-1. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range[a] (unitless)
Downstream (SWS-06A)	3	0.60-1.14
Downstream (SWS-06A)[b]	3 [c]	0.85-1.06
Downstream (SWS-06)	3	0.94-1.05
Downstream (SWS-06)[b]	3[c]	0.94-1.06
Reference (SWS-09)	3	1.51-1.56
Reference (SWS-09)[b]	3[c]	1.01-1.12

[a] The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
[b] The ORAP Phase II expanded the sediment investigation due to the lack of surface water.
[c] The three samples include a primary, duplicate, and triplicate.

In accordance with the Site-Specific ERMP for Fort Sill, Oklahoma, Annex 13 (ML16265A227) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, SWS-06A, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at Fort Sill are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-2 and 2-3.

Table 2-2. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-06A	6/7/2017	0.74 +/- 0.35
SWS-06A	9/7/2017	0.69 +/- 0.45
SWS-06A	11/29/2017	0.4 +/- 0.1
SWS-06A	2/27/2018	0.73 +/- 0.11
SWS-06A	5/30/2018	0.80 +/- 0.24
SWS-06A	9/11/2018	--- +/- ---
SWS-06A	12/12/2018	0.72 +/- 0.23

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
--- +/--- – Indicates surface water sample was not collected because water was not present during sampling.

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-06A	6/7/2017	0.70 +/- 0.29
SWS-06A	9/7/2017	0.95 +/- 0.33
SWS-06A	11/29/2017	0.9 +/- 0.2
SWS-06A	9/13/2018	1.0 +/- 0.2
SWS-06A	2/27/2018	1.1 +/- 0.2
SWS-06A	5/30/2018	0.95 +/- 0.19
SWS-06A	9/11/2018	1.0 +/- 0.2
SWS-06A	12/12/2018	1.2 +/- 0.3

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-3, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Fort Sill.

2.2 GROUNDWATER

Groundwater samples were collected during the ORAP Phase II assessment in 2006; however, the samples were not analyzed for radiological parameters (EA 2014). The existing groundwater monitoring wells are shown in Figure 1-2.

Presently, no groundwater monitoring wells are located at or near the RCA. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Fort Sill.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Sill does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedure (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Fort Sill will be coordinated with the Fort Sill Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-235 and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to the weight percentage of U-235 mass to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for the RCA by multiplying the entire mass of DU listed on the license for the installation (120 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Fort Sill RCA

Parameter		Default Value	Fort Sill FP 182/West Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	1.18×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	1.08×10^{-3}	
	U-238	N/A	0.18	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 140 ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.45	RESRAD Manual (DOE 2001) Table E-8 for Silt (Soil is cobbly loam from web soil survey)
Contaminated zone hydraulic conductivity (m/y)		10	1,090	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Contaminated zone b parameter		5.3	4.9	RESRAD Manual Table E.2 (DOE 2001) for Sandy Loam
Average annual wind speed (m/s)		2.0	7.3	**www.usa.com** for Fort Sill, OK
Precipitation rate (annual rainfall) (m/y)		1.0	0.89	**www.usa.com** for Fort Sill, OK
Saturated Zone				
Saturated zone total porosity		0.4	0.42	RESRAD Manual (DOE 2001) Table E-8 for Clay
Saturated zone effective porosity		0.2	0.06	RESRAD Manual (DOE 2001) Table E-8 for Clay
Saturated zone hydraulic conductivity (m/y)		100	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Saturated zone b parameter		5.3	10.4	RESRAD Manual (DOE 2001) Table E.2 for Silty Clay
Unsaturated Zone				
Unsaturated zone 1, total porosity		0.4	0.42	RESRAD Manual (DOE 2001) Table E-8 for Clay
Unsaturated zone 1, effective porosity		0.2	0.06	RESRAD Manual (DOE 2001) Table E-8 for Clay
Unsaturated zone 1, soil-specific b parameter		5.3	10.4	RESRAD Manual (DOE 2001) Table E.2 for Silty Clay
Unsaturated zone 1, hydraulic conductivity (m/y)		10	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Fort Sill RCA

RCA Layout Parameter	FP 182/West Range			
Distance to nearest normally occupied area (m)	3,200			
Bearing of X axis (degrees)	270 (south)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	4300	4332
Leafy vegetables plot	500	531.25	4334	4366
Pasture, silage growing area	500	600	4516	4616
Grain fields	500	600	4366	4466
Dwelling site	500	531.25	4200	4232
Surface-water body	500	800	4616	4916
Primary Contamination Parameter				
Length parallel to aquifer flow* (m)	142			
Atmospheric Transport Parameter				
Meteorological STAR file	OK_OKLAHOMA_CITY_TIN.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	3,200			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	3,616			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (m)	90			

* Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Fort Sill does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Fort Sill FP 182/West Range	0.021	0.013

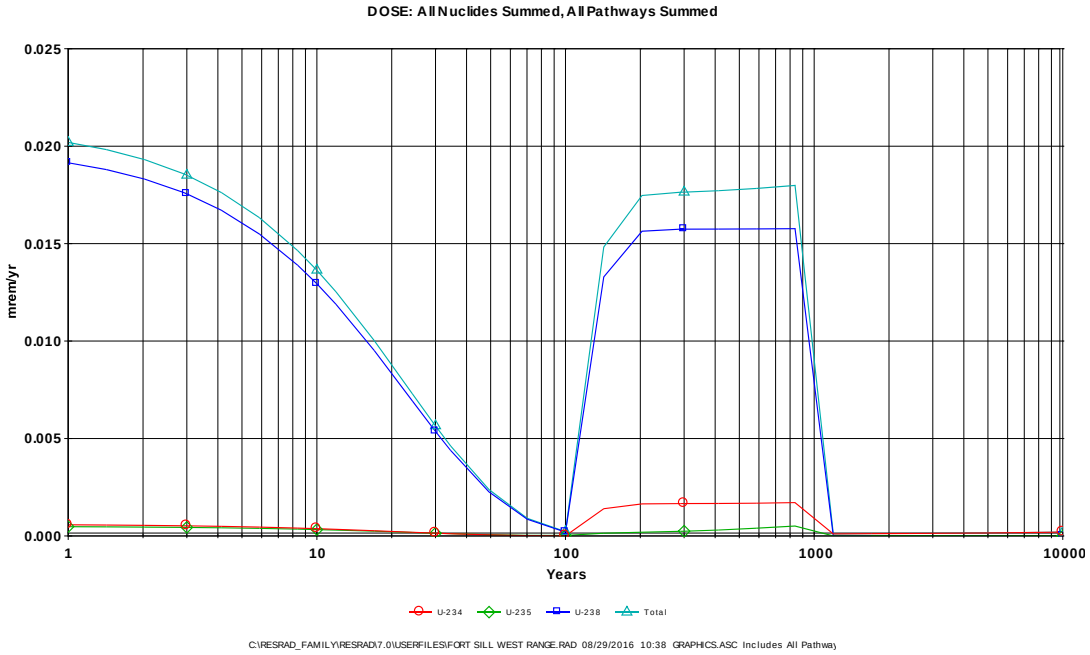
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

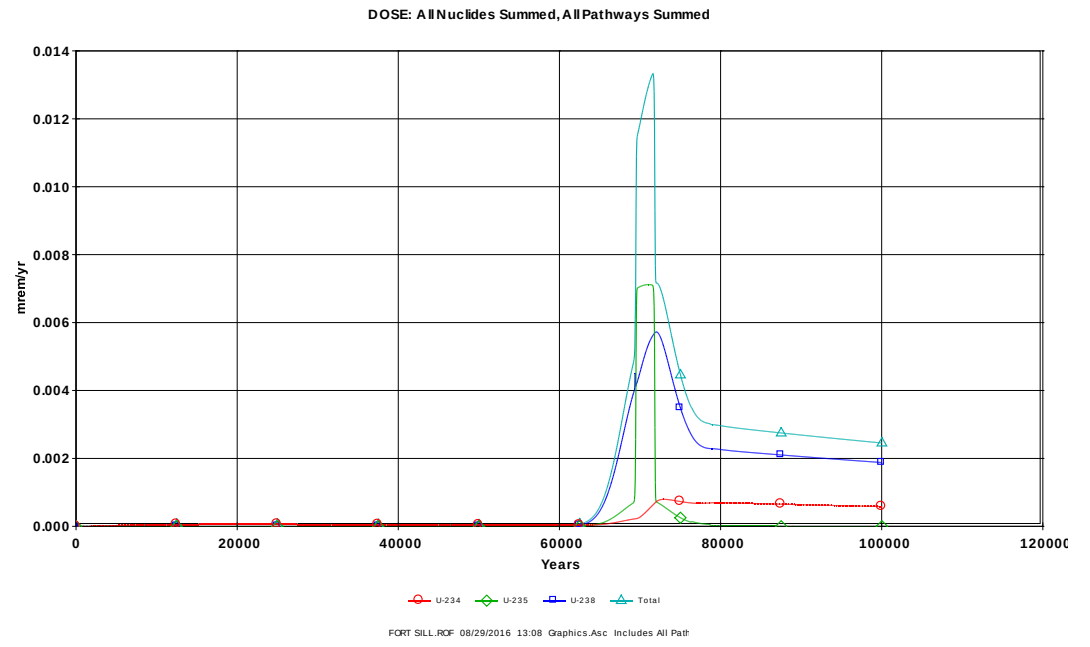
Figure 4-1. Residential Farmer Receptor Dose Graphs

Fort Sill FP 182/West Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN JOINT BASE LEWIS-MCCHORD, TACOMA, WASHINGTON ANNEX 14

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

November 2023

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
JBLM	Joint Base Lewis-McChord
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
OP	Observation Post
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020a) and describes the additional details related to Joint Base Lewis-McChord (JBLM) in Tacoma, Washington, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for JBLM, Tacoma, Washington, Annex 14 (ML21165A013) (U.S. Army 2020a).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at JBLM. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
Co-located surface water and sediment samples downstream (**AIA-SP02**) from the Range 52, OP9, and OP8 RCAs, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

JBLM is a 92,368-acre installation located in western Washington, approximately 9 miles south of Tacoma (Figure 1-1). JBLM occupies portions of Pierce and Thurston Counties. The entire installation is operational and includes 230 ranges.

Camp Lewis, the original name of Fort Lewis, was established in 1917, named after Meriwether Lewis of the Lewis and Clark Expedition. Camp Lewis was renamed Fort Lewis in 1927 after becoming property of the Federal Government. Tacoma Field, an airfield, was opened in 1930 and was renamed McChord Field in 1940, in honor of Colonel William Caldwell McChord. McChord Field separated from Fort Lewis after the U.S. Air Force separated from the U.S. Army in 1947 and was renamed McChord Air Force Base. In 1992, McChord Field became an Air Mobility Command Base. In 2010, McChord Air Force Base joined Fort Lewis to become JBLM under the 2005 Base Realignment and Closure Act. JBLM is currently a training and mobilization center for all services.

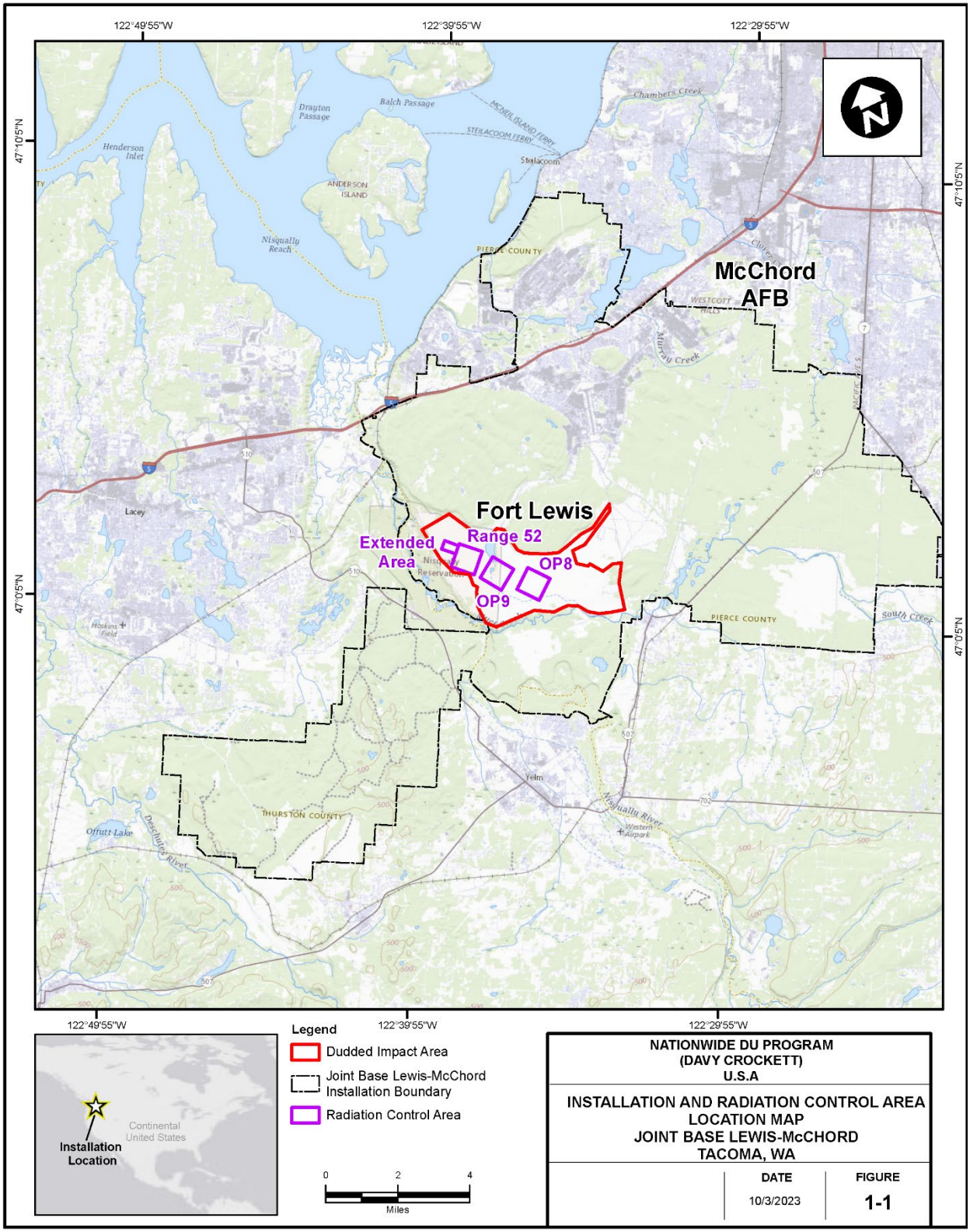

Figure 1-1. Installation and Radiation Control Area Location Map

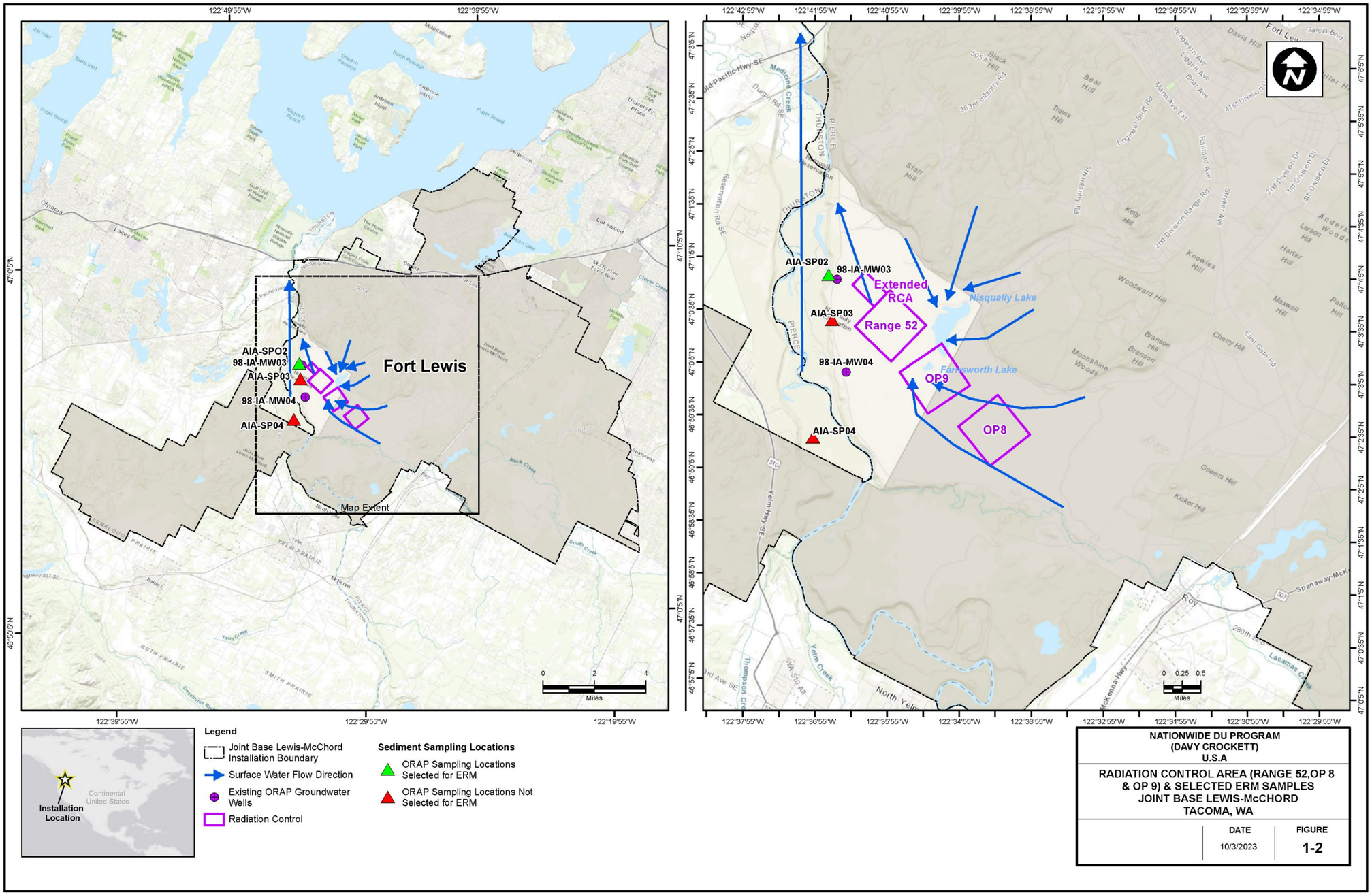

Figure 1-2. Radiation Control Area (Range 52, OP 8, and OP 9) and Selected ERM Samples

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An Archives Search Report (ASR) (USACE 2008) confirmed the presence of three ranges where the Davy Crockett weapons system was used at Fort Lewis, known as Range 52, Observation Post (OP)-8, and OP-9 (Figure 1-2). Three radiation control areas (RCAs) have been established for these ranges. Pursuant to the discovery of the remnants of four M101 spotting rounds in 2022, Amendment #8 (ML23201A019) (NRC 2023) extends a portion of the Range 52 RCA to encompass the locations of the M101 spotting rounds. The nearest normally occupied areas to the Range 52 RCA, OP-8 RCA, and OP-9 RCA are located approximately 1.4, 2.6, and 1.8 miles, respectively, southwest of the RCAs.

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU that was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968.

These installations include Fort Moore (formerly referred to as Fort Benning), Fort Liberty (formerly referred to as Fort Bragg), Fort Campbell, Fort Carson, Fort Eisenhower (formerly referred to as Fort Gordon), Fort Cavazos (formerly referred to as Fort Hood), Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Johnson (formerly referred to as Fort Polk), Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at JBLM; therefore, it is assumed that most, if not all, of the 340 kilograms (kg) of DU from the rounds fired into RCAs at JBLM and Yakima TA remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

JBLM is situated within the south Puget Sound region along Interstate-5, the major transportation corridor in western Washington. In general, the area where the RCAs is located in relatively level plain interrupted by well-rounded, isolated hills rising about 100 feet above the surrounding terrain.

According to the Environmental Assessment, Northwest Aviation Operations 160th Special Operations Aviation Regiment (U.S. Army 2012a), Andisols are the predominant soils along the Washington and Oregon Coast ranges, and along the Cascade Range. These soils are underlain by volcanic ash and cinders, and they commonly occur at high elevations in areas with past volcanic activity. They are productive soils but are somewhat prone to erosion because of low density. In the Puget Sound lowlands, Inceptisols are predominant. They are relatively young soils and lack well-defined profile characteristics. Their productivity is largely dependent on local site conditions and may be high where moisture is adequate. Inceptisols formed on hillsides may be very erodible without their native vegetation. The Environmental Assessment, Sniper Field Fire Range (U.S. Army 2012b) indicates that the soil textures at the Yakima Training Center, located northeast of Yakima, Washington, in close proximity to JBLM, are silt loam and loam (predominantly a sand and silt mixture with a low clay content).

Groundwater naturally discharges along the cliffs adjacent to the Puget Sound, in creek beds, and west of the Artillery Impact Area above the Nisqually River along the 7th Infantry Bluff. Due to the abruptness of the bluff and the elevation drop down to the Nisqually River, groundwater likely follows preferential pathways where perched groundwater discharges as springs emerging from the outcrops along the river. Surface water within the central portion of JBLM moves north and west toward Puget Sound and

the Nisqually River as overland flow. Therefore, the groundwater is unlikely to underflow the Nisqually River, and the expectation is that the river serves as a groundwater boundary.

JBLM lies principally within the Chambers Creek and Nisqually River basins. The RCAs lie within the Nisqually River basin, and the Nisqually River receives some surface water from the relatively flat plain where the Range 52 RCA is located. Surface water also drains to Farnsworth and Nisqually Lakes from the OP-8 and OP-9 RCAs, and a portion of the Range 52 RCA. Farnsworth Lake and a portion of Nisqually Lake are located on the OP-9 RCA. Two tributaries flow north and northwest through the OP-9 RCA toward Farnsworth Lake, as shown in Figure 1-2. Water egress from Farnsworth and Nisqually Lakes is not evident from the topography map.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the RCAs at JBLM are as follows:

- ***Surface Water Use***—The only potable water source of concern is at the Nisqually Clear Creek Fish Hatchery, located between JBLM and the Nisqually River. This hatchery is operated by the Nisqually Indian Tribe as part of Coho Salmon restoration efforts (U.S. Army 2014a).
- ***Recreational Use***—Recreational and fishing activities on and around JBLM occur in the Puget Sound and Nisqually River. Surface water and sediment in these recreational areas are potential pathways for human receptors.
- ***Sensitive Environments***—The Nisqually River is a sensitive habitat for salmon, and enters the Billy Frank Jr. Nisqually National Wildlife Refuge, which is located at the northwestern corner of JBLM.
- ***Habitat***—The RCAs are located in a prairie terrain with Douglas fir and oak tree encroachment. Fresh-water lakes, Farnsworth Lake and Nisqually Lake, are located in the prairie. The Nisqually River forms part of the western border of JBLM.
- ***Ecological Receptors***—Ecological receptors include habitat for Federal- and state-listed threatened and endangered species (e.g., American bald eagle, bull trout, chinook salmon, killer whale, mardon skipper, mazama pocket gopher, northern spotted owl, Taylor's checkerspot, streaked horned lark, and water howellia).
- ***Groundwater Use***—JBLM has production wells used for drinking water located within the installation. Because the Nisqually River is considered to serve as a groundwater discharge boundary, potable wells across the river on the west side are not considered viable exposure routes for human receptors.

Human receptors identified at JBLM include downgradient and off-range residents, recreational users, and users of the potable water at the Nisqually Clear Creek Fish Hatchery. Ecological receptors identified at JBLM include wetlands and threatened and endangered species downstream.

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCAs or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Range 52, OP-8, and OP-9 RCAs at JBLM are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of one sample from a location downstream from the RCAs in JBLM (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., flooding). The surface water and sediment sampling location at JBLM was selected based on the surface water hydrology of the Nisqually watershed, the locations of the three RCAs, and the potential for DU contribution, as follows:

- ***AIA-SP02***—This sampling point is located in the pathway from the RCAs to the Nisqually Clear Creek Fish Hatchery and to the Nisqually River.

The Operational Range Assessment Program (ORAP) Phase I Qualitative Assessment Report Addendum (U.S. Army 2014a) documents the location of these historical sampling points (Figure 1-2); however, analytical sampling was not completed as part of the ORAP Phase I. The ORAP Phase I assessment concluded that a source-pathway-receptor interaction was unlikely and environmental sampling of sediment was not necessary. The following locations were not selected for evaluation of the Range 52, OP9, and OP8 RCAs based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***AIA-SP03 and AIA-SP04***—These sampling points are not located in the pathway from the RCAs to the Nisqually Clear Creek Fish Hatchery. These sampling points are not relevant because sampling point AIA-SP02 is sufficient to monitor surface water runoff to both the Nisqually Clear Creek Fish Hatchery and to the Nisqually River.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCAs indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify the NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for JBLM, Tacoma, Washington, Annex 14 (ML16265A228) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling location, AIA-SP02, in 2017, 2018, 2019, and 2020. Pursuant to Amendment 6, in 2021 and 2022, the Army changed the frequency of the surface water and sediment sampling from quarterly to semiannually in 2021 and semiannual sampling continued in 2022 (ML21165A043) (U.S. Army 2021a). The concentrations of total and isotopic uranium in surface water and sediment from the environmental radiation monitoring (ERM) sampling events at JBLM are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018); Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019); Radiation Monitoring Report, Summary of Results for 2019 Sampling Events (ML20138S110) (U.S. Army 2020b); Radiation Monitoring Report, Summary of Results for 2020 Sampling Events (ML21126A051) (U.S. Army 2021b); Radiation Monitoring Report, Summary of Results for 2021 Sampling Events (ML22220A292) (U.S. Army 2022); and Radiation Monitoring Report, Summary of Results for 2022 Sampling Events (ML19115A040) (U.S. Army 2023). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio[a] (unitless)
AIA-SP02	5/22/2017	ND
AIA-SP02	9/14/2017	ND
AIA-SP02	12/4/2017	ND
AIA-SP02	2/27/2018	0.73 +/- 0.11
AIA-SP02	5/30/2018	0.80 +/- 0.24
AIA-SP02	9/11/2018	--- +/- ---
AIA-SP02	12/12/2018	0.72 +/- 0.23
AIA-SP02	2/21/2019	ND
AIA-SP02	5/20/2019	ND
AIA-SP02	9/19/2019	ND
AIA-SP02	10/21/2019	ND
AIA-SP02	3/16/2020	ND
AIA-SP02	6/29/2020	0.48 +/- 0.21
AIA-SP02	9/14/2020	ND
AIA-SP02[b]	11/9/2020	ND
AIA-SP02	3/22/2021	NC
AIA-SP02	9/20/2021	NC
AIA-SP02	3/14/2022	NC
AIA-SP02	8/8/2022	NC

[a]The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

[b]Indicates a duplicate sample was collected to fulfill QA/QC requirements and was combined into a single reported result.

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

--- +/--- – Indicates surface water sample was not collected because water was not present during sampling.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017, 2018, 2019, 2020, 2021, and 2022 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio[a] (unitless)
AIA-SP02	5/22/2017	1.0 +/- 0.4
AIA-SP02	9/14/2017	0.76 +/- 0.36
AIA-SP02	12/4/2017	0.90 +/- 0.36
AIA-SP02	2/27/2018	1.1 +/- 0.2
AIA-SP02	5/30/2018	0.95 +/- 0.19
AIA-SP02	9/11/2018	1.0 +/- 0.2
AIA-SP02	12/12/2018	1.2 +/- 0.3
AIA-SP02	2/21/2019	0.94 +/- 0.3
AIA-SP02	5/20/2019	1.1 +/- 0.5
AIA-SP02	9/19/2019	0.96 +/- 0.5
AIA-SP02	10/21/2019	0.57 +/- 0.3
AIA-SP02	3/16/2020	0.88 +/- 0.34
AIA-SP02	6/29/2020	0.66 +/- 0.29
AIA-SP02	9/14/2020	1.4 +/- 0.6
AIA-SP02[b]	11/9/2020	1.2 +/- 0.3
AIA-SP02	3/22/2021	0.71 +/- 0.3
AIA-SP02	9/20/2021	0.96 +/- 0.4
AIA-SP02	3/14/2022	0.53 +/- 0.26
AIA-SP02	8/08/2022	NC

[a]The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

[b]Indicates a duplicate sample was collected to fulfill QA/QC requirements and was combined into a single reported result.

ND/NC – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at JBLM.

2.2 GROUNDWATER

Presently, two groundwater monitoring wells are located near the RCAs. Groundwater in the shallowest aquifer flows toward the Nisqually River away from the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020a), groundwater sampling is not planned for JBLM.

Based on the conclusions of the ORAP Phase I assessment, a Phase II assessment was not conducted at JBLM (U.S. Army 2014a). It was determined that the source-pathway-receptor interaction was unlikely and environmental sampling of groundwater was unnecessary.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among

the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014b]). The Installation Commander will then decide whether to allow the collection. Otherwise, JBLM does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020a).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to JBLM will be coordinated with the JBLM Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (340 kg for JBLM and Yakima TA) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity (Ci/g)	Mass Abundance (%)[b]
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	6×10^{-7}	100

[a]10 CFR 20, Appendix B, Footnote 3.
[b]Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for JBLM RCAs

Parameter		Default Value	JBLM Range 52	JBLM Range OP-8	JBLM Range OP-9	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone						
Soil concentrations (pCi/g)	U-234	N/A	2.65×10^{-2}	3.35×10^{-2}	3.35×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	2.43×10^{-3}	3.06×10^{-3}	3.06×10^{-3}	
	U-238	N/A	0.40	0.51	0.51	
Area of contaminated zone (m^2)		10,000	1,261,416	1,000,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	0	ORAP Phase I Periodic Review document (U.S. Army 2014a) indicates depth to groundwater is 10 feet bgs
Length parallel to aquifer flow (m)		100	1123	1,000	1,000	Assuming groundwater flows to Nisqually River
Contaminated zone total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b])
Contaminated zone hydraulic conductivity (m/y)		10	227	227	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Contaminated zone b parameter		5.3	5.3	5.3	5.3	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Average annual wind speed (m/s)		2.0	4.5	4.5	4.5	www.usa.com for Lakewood, WA
Precipitation rate (annual rainfall) (m/y)		1.0	1.27	1.27	1.27	www.usa.com for Lakewood, WA
Irrigation rate (m/y)		0.2	0.2	0.2	0.2	
Watershed area for nearby stream or pond (m^2)		1,000,000	1,261416	1,000,000	1,000,000	Total RCA
Saturated Zone						
Density of saturated zone (g/cm^3)		1.5	1.5	1.5	1.5	Assumed same as contaminated zone density
Saturated zone total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b])
Saturated zone effective porosity		0.2	0.20	0.20	0.20	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	227	227	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Saturated zone b parameter		5.3	5.3	5.3	5.3	RESRAD Manual (DOE 2001) Table E.2 for Silty Loam
Unsaturated Zone						
Unsaturated zone 1, total porosity		0.4	0.45	0.45	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt (Silty Loam determined from Yakima Training Center Sniper Field Fire Range EA Section 3.3 [U.S. Army 2012b])
Unsaturated zone 1, effective porosity		0.2	0.20	0.20	0.20	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	5.3	5.3	5.3	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam
Unsaturated zone 1, hydraulic conductivity (m/y)		10	227	227	227	RESRAD Manual Table E.2 (DOE 2001) for Silty Loam

*See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for JBLM RCAs

RCA Layout Parameter	JBLM Range 52				JBLM Range OP-8				JBLM Range OP-9			
Distance to nearest normally occupied area (m)	2,250				4,200				2,900			
Bearing of X axis (degrees)	315 (southwest)				315 (southwest)				315 (southwest)			
X dimension of primary contamination (m)	1,123				1,000				1,000			
Y dimension of primary contamination (m)	1,123				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	2350	2382	500	531.25	4300	4332	500	531.25	3000	3032
Leafy vegetables plot	500	531.25	2384	2416	500	531.25	4334	4366	500	531.25	3034	3066
Pasture, silage growing area	500	600	2566	2666	500	600	4516	4616	500	600	3216	3316
Grain fields	500	600	2416	2516	500	600	4366	4466	500	600	3066	3166
Dwelling site	500	531.25	2250	2282	500	531.25	4200	4232	500	531.25	2900	2932
Surface-water body	500	800	2666	2966	500	800	4616	4916	500	800	3316	3616
Atmospheric Transport Parameter												
Meteorological STAR file	WA_SEATTLE_TACOMA.str				WA_SEATTLE_TACOMA.str				WA_SEATTLE_TACOMA.str			
Groundwater Transport Parameter												
Length parallel to aquifer flow (m)	325				325				325			
Distance to well (parallel to aquifer flow)	1127				3200				1900			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1543				3616				2316			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	135				135				135			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at JBLM does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

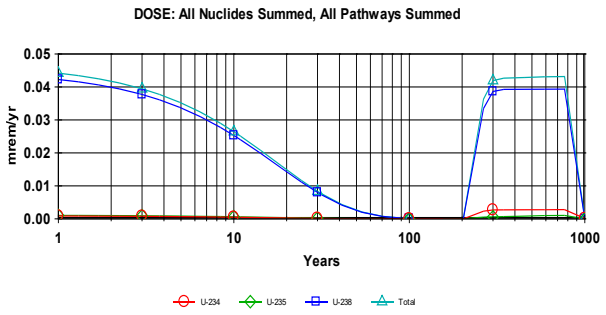
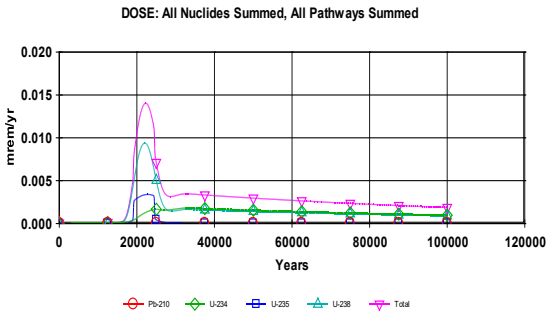
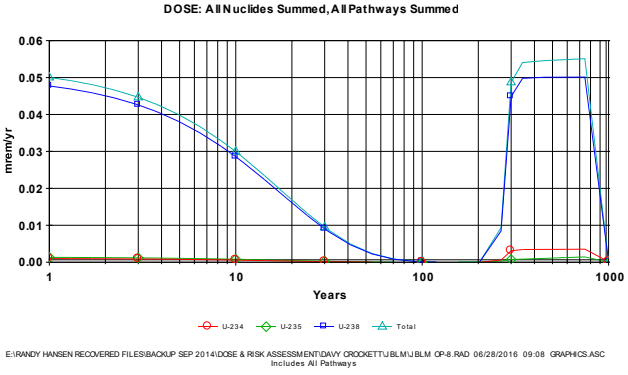
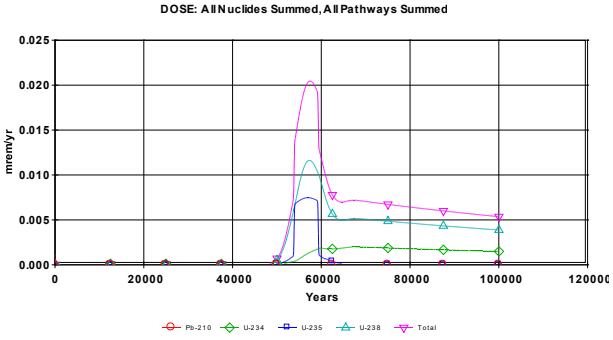
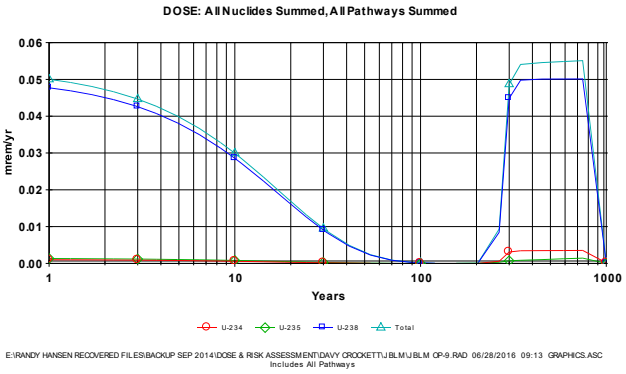
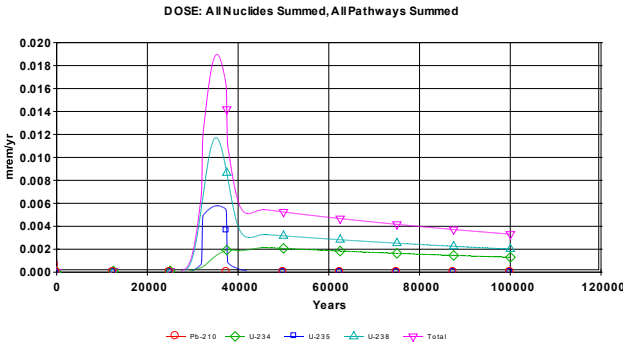
Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
JBLM Range 52	0.047	0.014
JBLM OP-8	0.060	0.021
JBLM OP-9	0.060	0.020

[a]The onsite residential farmer receptor resides on the RCA.
[b]The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD)

Figure 4-1. Residential Farmer Receptor Dose Graphs

RCA Onsite (RESRAD)	RCA Offsite (RESRAD-OFFSITE)
JBLM Range 52	
	
JBLM OP-8	
	
JBLM OP-9	
	

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Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4]	
				(Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7×10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\ \text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ + (3.36 \times 10^{-7}\ \text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN YAKIMA TRAINING CENTER, WASHINGTON ANNEX 15

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DGPS	Differential Global Positioning System
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
JBLM	Joint Base Lewis-McChord
kg	Kilogram
m^2	Square Meters
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
TC	Training Center
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Yakima Training Center (TC) in Washington State, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for Yakima TC, Washington, Annex 15 (ML16265A229) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Yakima TC. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Three co-located surface water and sediment samples downstream from the Ranges 17 and 20 RCAs (**SWS-01**); Ranges 14, 17, and 20 RCAs (**SWS-02**); and from the Range 14 RCA (**SWS-05**), as shown in Figures 1-2 and 1-3 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Yakima TC is a 327,231-acre installation located in south central Washington State, approximately 100 miles southeast of Joint Base Lewis-McChord (JBLM) and 4 miles east of Selah, Washington (Figure 1-1). Selah consists of commercial and small businesses along with residential communities.

Yakima TC has been in use since 1942 and includes 78 ranges that are operational and 2,481 acres that are other than operational, which includes the cantonment area and Selah Canyon. Three radiation control areas (RCAs) are located within Yakima TC: Range 14 (Figure 1-2), Range 17 (Figure 1-3), and Range 20 (Figure 1-3). All branches of the U.S. Army train at Yakima TC to sustain and improve unit readiness for both wartime and contingency operations. Yakima TC currently is a sub-installation of JBLM and houses several military and Federal Government tenants, including the Washington Army National Guard Mobilization and Training Equipment Site, Marine and Army Reserve Centers, and the Yakima Research Station. The installation's training facilities are also used by other Federal agencies and local law enforcement (Malcolm Pirnie 2008).

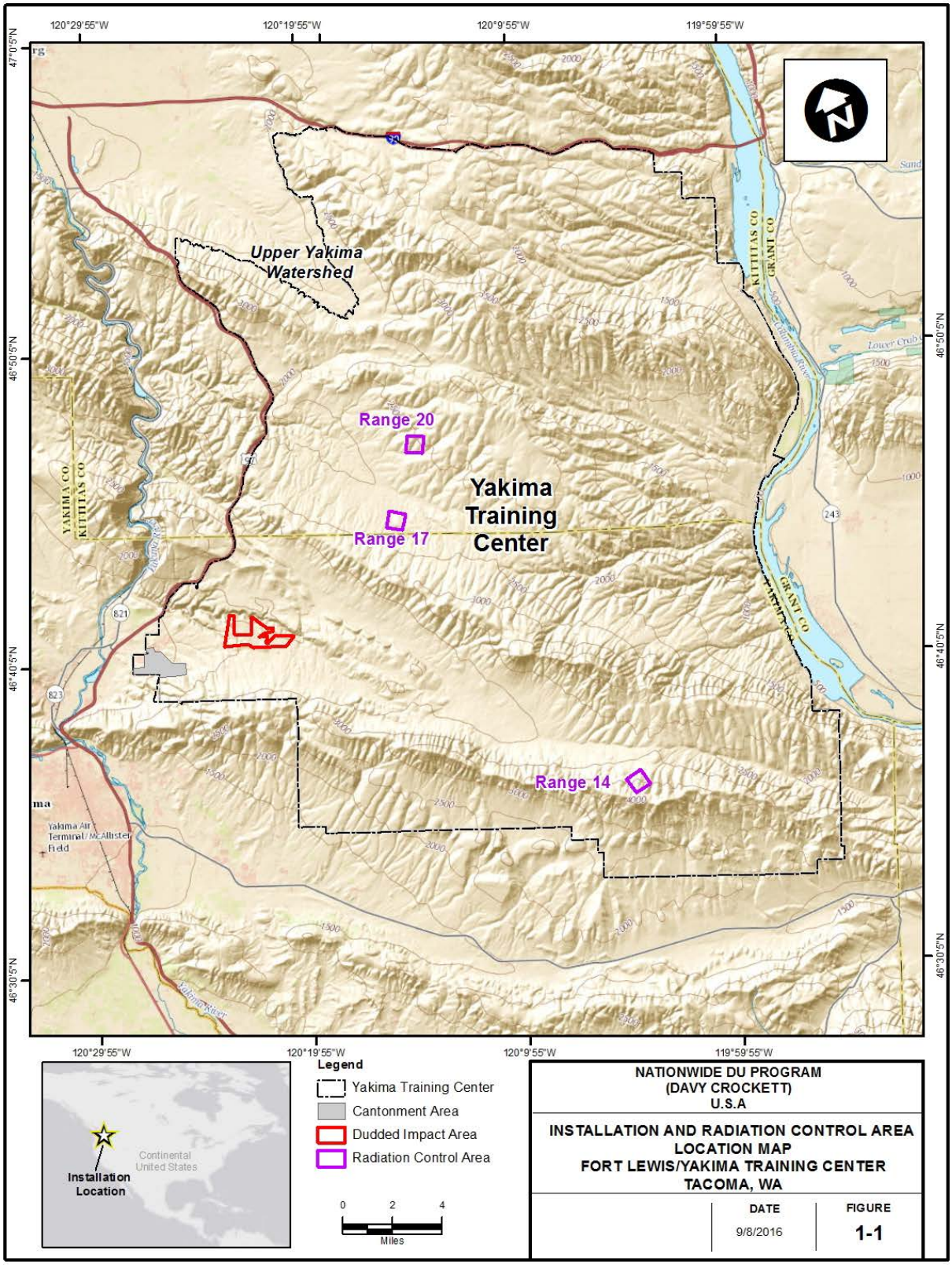


Figure 1-1. Installation and Radiation Control Area Location Map

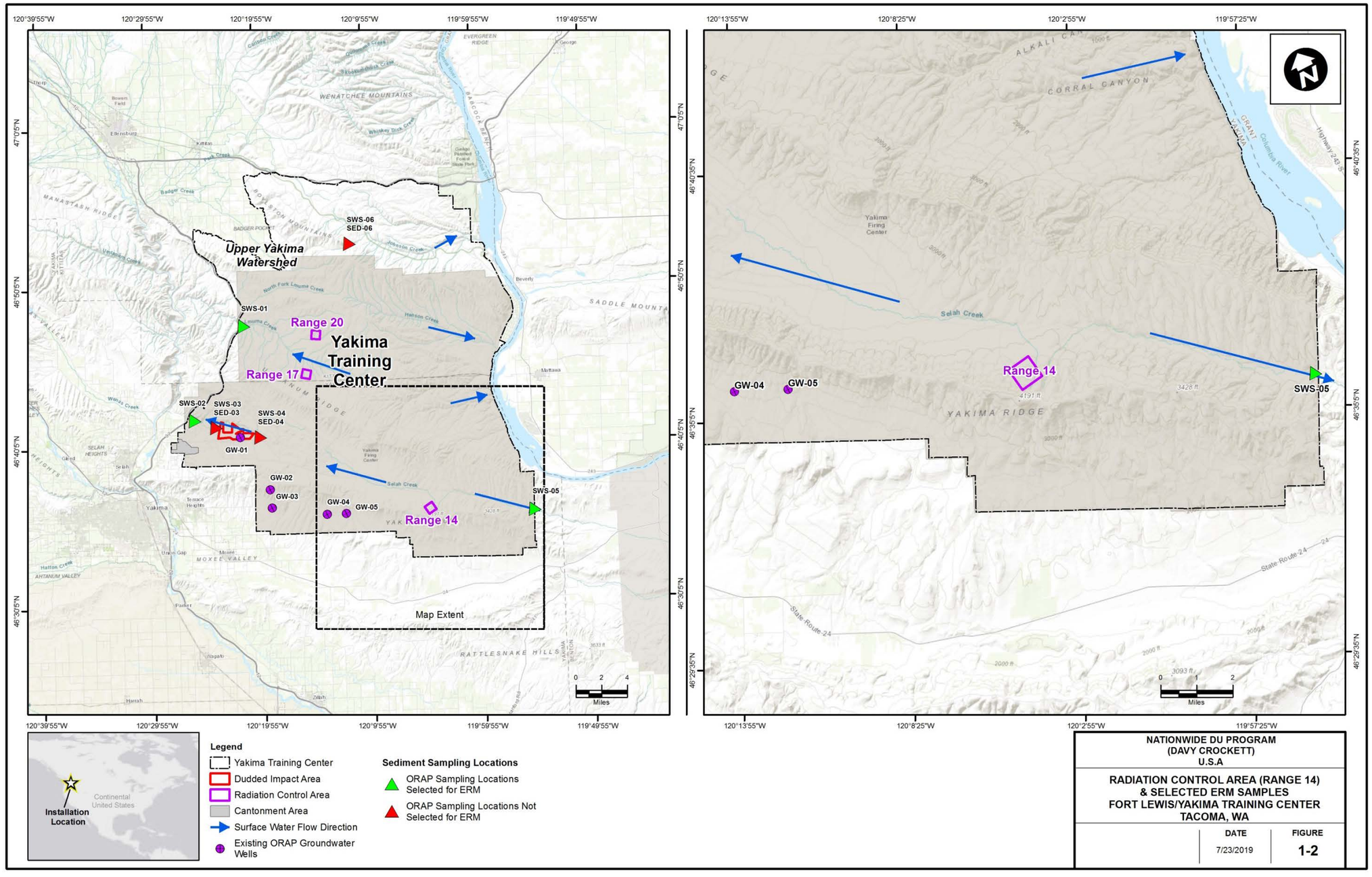


Figure 1-2. Radiation Control Area (Range 14) and Selected ERM Samples

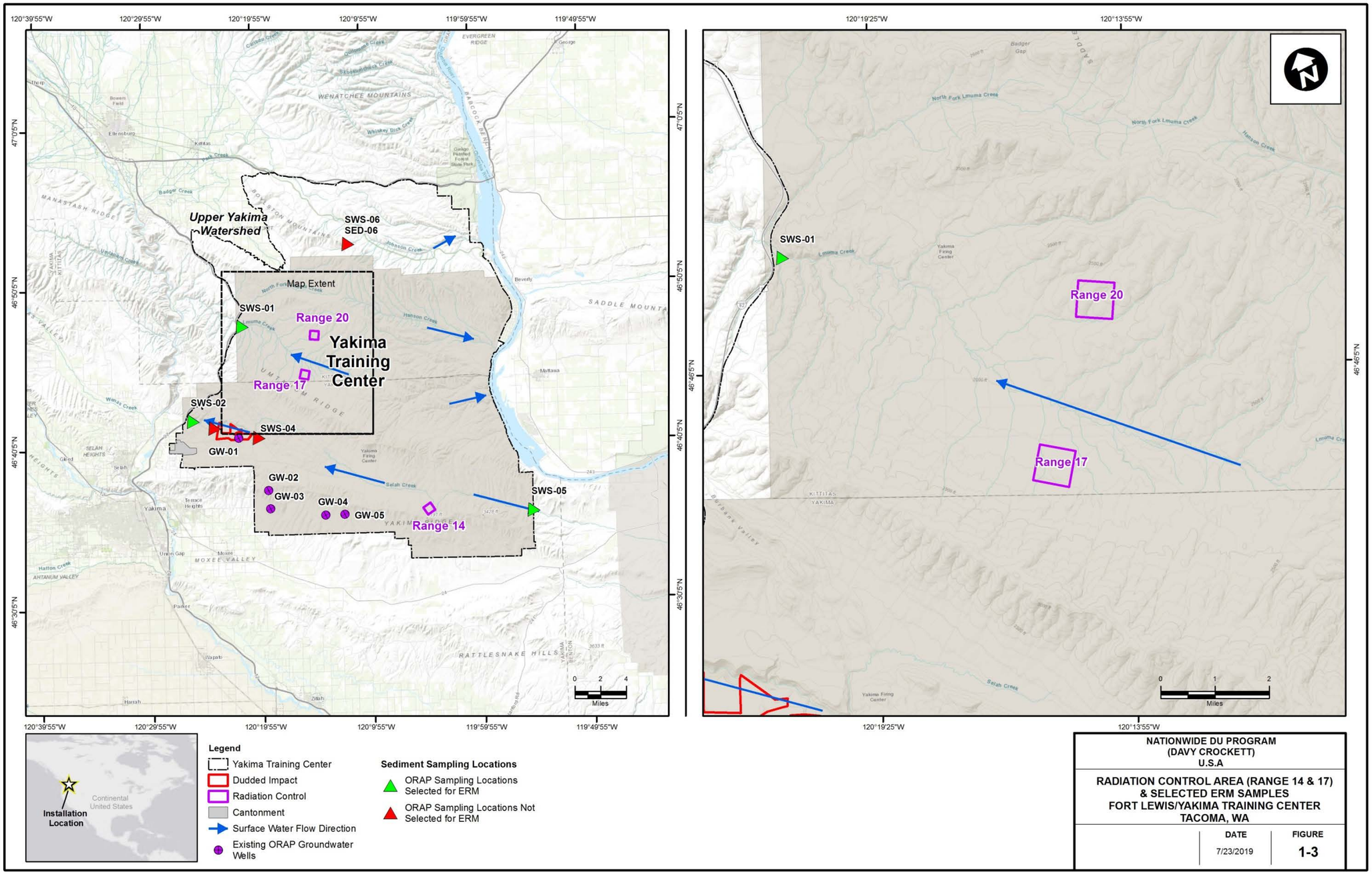


Figure 1-3. Radiation Control Area (Ranges 14 and 17) and Selected ERM Samples

1.3 HISTORICAL INFORMATION

The M101 spotting round contains DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), JBLM (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at Yakima TC; therefore, it is assumed that most, if not all, of the 340 kilograms (kg) of DU from the rounds fired into RCAs at JBLM and Yakima TC remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Yakima TC is located in the Columbia Basin of Washington State. The region is semiarid and characterized by cool winters with light snowfall and hot, dry summers. Topography at Yakima TC varies from low plains to mountains that have been modified by glaciers and flooding, which created a network of drainages. Yakima TC drains into two major basins: the Columbia River Basin east of the installation and the Yakima River Basin to the west. The installation is further divided into 10 watersheds: Badger, Lmuma, Selah, Moxee, and Cold Creek watersheds (which drain toward the Yakima River); and Corral, Alkali, Hanson, Johnson, and Middle Creek watersheds (which drain toward the Columbia River). Stream flow within the installation boundary is attributed to winter precipitation, high flood flows during spring snowmelt, and summer thunderstorms.

Yakima TC lies within the Yakima Fold Belt, which is a transitional zone between the Cascade Mountains and Columbia Plateau basalt that is identifiable in Figure 1-1. The Columbia River Basalt Group is an aquifer system consisting of basin-fill deposits occurring in six structural-sedimentary basins. Groundwater in the different hydrogeological units occurs under perched, unconfined, semiconfined, and confined conditions. The fold is characterized by a series of asymmetrical, elongated, tightly folded, southeast-trending synclines and anticlines. The extensive folding creates a complex groundwater system. Groundwater is present in four stratigraphic units of the Yakima Basalt Group (in ascending order): Grande Ronde Basalt, Wanapum Basalt, Saddle Mountain Basalt, and the unconsolidated overburden. The Wanapum Basalt and, to a lesser extent, the Grande Ronde Basalt are the primary aquifers utilized for public drinking water supply. Groundwater flows laterally along flow tops through vesicular and fractured zones, as well as through sedimentary beds between flows. Groundwater also flows vertically through the basalts along joints that formed as the rock solidified from molten lava. The depth to groundwater ranges from 20 feet below ground surface (bgs) in valleys to more than 200 feet bgs at higher elevations. Shallow groundwater flow is generally westward and eastward, following topography from higher elevations at the center of the installation, toward the Yakima River and Columbia River, respectively. The Upper Yakima watershed is north of the Lmuma Creek and Yakima River. Deeper groundwater flow is generally eastward toward the Columbia River. Deeper aquifers are recharged mainly from the area west of the installation and are generally confined or semiconfined, whereas shallower unconfined aquifers are recharged primarily by precipitation falling on ridge crests and rubble slopes, as well as by surface water infiltration in some creek beds. Shallow groundwater flow refers specifically to the overburden and deeper flow represents the Saddle Mountain, Wanapum, and Grande Ronde Basalt aquifers.

Two ridges are within the operational area of Yakima TC: the Umtanum and Yakima Ridge. The two ridges define an over-turned anticline, which creates a trough, channeling surficial groundwater flow

west toward the Yakima River. In addition, the Yakima Ridge may create a hydrogeologic barrier, preventing groundwater from flowing southwest toward wells located within 4 miles downgradient. However, joints within the ridgeline may act as conduits and facilitate groundwater movement from the RCA area, southwest toward the Yakima River and to public supply wells. Lateral groundwater flow beneath the ranges at Yakima TC is mainly contained in the interflow material between major basalt flows, and the direction of groundwater flow is predominantly parallel to the structural dip of the basalt (USGS 2009). A large amount of vertical fracturing of the basalt into colonnades occurs, which can tie the more horizontal layers and inhibit flow. The structural gradient is affected by the surface topography and regional deformation, and this is reflected in the flow lines that can be derived from regional groundwater contours, which are nearly perpendicular to the ridge lines. Groundwater and surface water within Yakima TC are interconnected through springs present where ridges or incised stream valleys intercept aquifers.

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified routes to human and/or ecological receptors. Specific details regarding the potential receptors for RCAs at Yakima TC are as follows:

- ***Surface Water Use***—Surface water on and surrounding Yakima TC, including the Yakima River to the west and the Columbia River to the east and their tributaries, are used for recreational purposes such as sport fishing and swimming, as well as agricultural purposes such as irrigation. These streams also contain sensitive environments, habitats, and ecological receptors.
- ***Recreational Use***—Recreational activities occurring within 15 miles of and downstream from Yakima TC include fishing in the Columbia River and Yakima River. Kiddie Pond, within the cantonment area, is open to children for fishing.
- ***Sensitive Environments***—Sensitive environments at and around Yakima TC include riparian and wetland areas, wildlife protection areas, and habitats used by federally and state threatened and endangered species. Riparian and wetland areas are located along springs and creeks within Yakima TC with the most sensitive areas being Selah Creek, Lmuma Creek, Alkali Creek, Hanson Creek, and the western bank of the Columbia River.
- ***Habitat***—Riparian areas and wetlands occur along portions of perennial or intermittent streams, primarily along the Columbia River and Selah Creek. Riparian areas comprise only a small portion the land and are used disproportionately more by wildlife than other habitat. Upland shrub-steppe regions make up 95 percent of the Yakima TC habitat.
- ***Ecological Receptors***—There are both state and federally threatened and endangered species present on Yakima TC. Sensitive fish species on the Yakima TC include the Middle Columbia steelhead (*Oncorhynchus mykiss*), Upper Columbia steelhead (*Oncorhynchus mykiss*), and the Upper Columbia spring Chinook (*Oncorhynchus tshawytscha*). Additional federally and state threatened species include the American bald eagle (*Haliaeetus leucocephalus*), Ferruginous hawk (*Buteo regalis*), and the greater sage grouse (*Centrocercus urophasianus phaios*).
- ***Groundwater Use***—Groundwater within 4 miles downgradient from RCA ranges at Yakima TC is used for public and private drinking water supply. Off-installation public and private drinking water supply sources of concern include those in Selah, Yakima, and unincorporated areas of Yakima and Kittias Counties.

Potential human receptors include those within Yakima TC and near Yakima River relying on potential public and private wells within 15 miles from the RCA for drinking water. Ecological receptors include sensitive environments (e.g., wetlands and anadromous fish habitat).

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for Yakima TC are discussed in the following sections.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the semiannual collection of samples from each of the three locations downstream from the RCAs on the Yakima TC (Figures 1-2 and 1-3) where surface water flows intermittently throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling locations at Yakima TC were selected based on the surface water hydrology of Selah Creek, Lmuma Creek, and the Upper Yakima Watershed for Range 14, Range 17, and Range 20 RCAs and the potential for DU contribution, and are located as follows:

- ***SWS-01***—The selected sampling point is located on Lmuma Creek in the Upper Yakima River watershed downstream from Ranges 17 and 20 RCAs where Lmuma Creek exits the installation.
- ***SWS-02***—The selected sampling point is located on Selah Creek in the Upper Yakima watershed downstream from Ranges 14, 17, and 20 RCAs where Selah Creek exits the installation.
- ***SWS-05***—The selected sampling point is located on Selah Creek downstream from RCA Range 14 where Selah Creek exits the installation to the Columbia River.

Additional locations were sampled during the Operational Range Assessment Program (ORAP) Phase II assessment (Figures 1-2 and 1-3). These locations were not selected for evaluation of the Yakima TC RCAs based on the surface water hydrology and potential for DU contribution, and are located as follows:

- ***SWS-03***—The sampling point is located on Selah Creek upstream from the Range 14 RCA. Even though SWS-03 is located downstream from the Range 14 RCA, the potential for DU migration off the installation will be captured (if present) by sampling farther upstream at SWS-02 located on the installation boundary.
- ***SWS-04***—The sampling point is located on Selah Creek upstream from the Range 14 RCA. Even though SWS-04 is located downstream from the Range 14 RCA, the potential for DU migration off the installation will be captured (if present) by sampling farther upstream at SWS-02 located on the installation boundary.
- ***SWS-06***—The sampling point is located west of the Columbia River and was used as a reference sample. This reference sampling location is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios.

Surface water and sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCAs indicate that uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The following locations were sampled during the ORAP Phase II assessment in 2012 and analyzed for uranium in sediment (EA 2013). The range of U-238/U-234 activity ratios from the May, June, and September 2012 sampling events are presented in Table 2-1.

Table 2-1. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2012 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
Lmuma Creek (SED-01)	3	0.77-1.09
Selah Creek (SED-02)	3	0.43-0.90
Selah Creek (SED-03)	3	0.81-0.92
Selah Creek (SED-04)	3	0.93-1.02
Cold Creek (SED-05)	3	0.71-1.18
Foster Creek (Reference) (SED-06)	3	0.69-0.98

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for Yakima TC, Washington, Annex 15 (ML16265A228) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, SWS-01, SWS-02, and SWS-05, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the environmental radiation monitoring (ERM) sampling events at Yakima TC are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2019) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-2 and 2-3.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-3, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water or sediment at Yakima TC.

Table 2-2. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01	5/24/2017	0.29 +/- 0.1
SWS-02	5/24/2017	0.47 +/- 0.15
SWS-05	5/24/2017	0.65 +/- 0.27
SWS-01	8/23/2017	0.0060 +/- 0.0018
SWS-02	8/23/2017	--- +/- ---
SWS-05	8/23/2017	0.081 +/- 0.035
SWS-01	11/29/2017	0.41 +/- 0.18
SWS-02	11/29/2017	0.57 +/- 0.2
SWS-05	11/29/2017	0.73 +/- 0.35
SWS-01	2/28/2018	0.48 +/- 0.15
SWS-02	2/28/2018	0.56 +/- 0.16
SWS-05	2/28/2018	0.53 +/- 0.23
SWS-01	6/12/2018	0.68 +/- 0.37
SWS-02	6/12/2018	--- +/- ---
SWS-05	6/12/2018	0.54 +/- 0.34
SWS-01	9/5/2018	0.45 +/- 0.19
SWS-02	9/5/2018	--- +/- ---
SWS-05	9/5/2018	0.23 +/- 0.14
SWS-01	12/14/2018	0.15 +/- 0.08
SWS-02	12/14/2018	0.42 +/- 0.17
SWS-05	12/14/2018	0.087 +/- 0.037

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

--- +/--- – Indicates surface water sample was not collected because water was not present during sampling.

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01	5/24/2017	0.44 +/- 0.11
SWS-02	5/24/2017	0.52 +/- 0.13
SWS-05	5/24/2017	0.73 +/- 0.28
SWS-01	8/23/2017	0.56 +/- 0.14
SWS-02	8/23/2017	0.58 +/- 0.12
SWS-05	8/23/2017	0.84 +/- 0.24
SWS-01	11/29/2017	0.42 +/- 0.07
SWS-02	11/29/2017	0.68 +/- 0.21
SWS-05	11/29/2017	0.90 +/- 0.31
SWS-01	2/28/2018	0.93 +/- 0.28
SWS-02	2/28/2018	0.82 +/- 0.23
SWS-05	2/28/2018	1.0 +/- 0.3
SWS-01	6/12/2018	0.70 +/- 0.21
SWS-02	6/12/2018	0.65 +/- 0.15
SWS-05	6/12/2018	0.72 +/- 0.22
SWS-01	9/5/2018	0.84 +/- 0.3
SWS-02	9/5/2018	0.70 +/- 0.2
SWS-05	9/5/2018	0.86 +/- 0.28

Table 2-3. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events (Continued)

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01	12/14/2018	0.54 +/- 0.14
SWS-02	12/14/2018	0.74 +/- 0.19
SWS-05	12/14/2018	0.87 +/- 0.25

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

2.2 GROUNDWATER

Groundwater samples collected during the ORAP Phase II assessment groundwater sampling in October 2010 were analyzed for explosives and perchlorate and not analyzed for uranium (EA 2013). The existing groundwater wells are shown in Figures 1-2 and 1-3.

Presently, no groundwater monitoring wells are located at or near the RCAs. Since surface water is known to recharge groundwater, any DU potentially present in surface water that could impact groundwater would likely have been detected through surface water and sediment sampling. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for Yakima TC.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Yakima TC does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCAs have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support this Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Yakima TC will be coordinated with the Yakima TC Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235 and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the streambeds should be selected where the surface water flow is

low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (340 kg for JBLM and Yakima TC) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Yakima Training Center RCAs

Parameter		Default Value	Range 14	Range 17	Range 20	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone						
Soil concentrations (pCi/g)	U-234	N/A	3.35×10^{-2}	3.35×10^{-2}	3.35×10^{-2}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	3.06×10^{-3}	3.06×10^{-3}	3.06×10^{-3}	
	U-238	N/A	0.51	0.51	0.51	
Area of contaminated zone (m^2)		10,000	1,000,000	1,000,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	0	Depth to groundwater is generally 20 to 200 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	1,000	Groundwater flows east/west across RCAs
Contaminated zone total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Contaminated zone hydraulic conductivity (m/y)		10	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Contaminated zone b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Average annual wind speed (m/s)		2.0	7.4	7.4	7.4	**www.usa.com for Yakima, WA**
Precipitation rate (annual rainfall) (m/y)		1.0	0.45	0.45	0.45	**www.usa.com for Yakima, WA**
Saturated Zone						
Saturated zone total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Saturated zone effective porosity		0.2	0.28	0.28	0.28	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Saturated zone hydraulic conductivity (m/y)		100	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand
Saturated zone b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated Zone						
Unsaturated zone 1, total porosity		0.4	0.34	0.34	0.34	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Unsaturated zone 1, effective porosity		0.2	0.28	0.28	0.28	RESRAD Manual Table E.8 (DOE 2001) for Fine Gravel
Unsaturated zone 1, soil-specific b parameter		5.3	4.05	4.05	4.05	RESRAD Manual Table E.2 (DOE 2001) for Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	5,550	5,550	5,550	RESRAD Manual Table E.2 (DOE 2001) for Sand

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Yakima Training Areas RCAs

RCA Layout Parameter	Range 14				Range 17				Range 20			
Distance to nearest normally occupied area (m)	12,000				9,000				6,000			
Bearing of X axis (degrees)	180 (east)				135 (northeast)				180 (east)			
X dimension of primary contamination (m)	1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	13,100	13,132	500	531.25	10,100	10,132	500	531.25	7,100	7,132
Leafy vegetables plot	500	531.25	13,134	13,166	500	531.25	10,134	10,166	500	531.25	7,134	7,166
Pasture, silage growing area	500	600	13,316	13,416	500	600	10,316	10,416	500	600	7,316	7,416
Grain fields	500	600	13,166	13,266	500	600	10,166	10,266	500	600	7,166	7,266
Dwelling site	500	531.25	13,000	13,032	500	531.25	10,000	10,032	500	531.25	7,000	7,032
Surface-water body	500	800	13,416	13,716	500	800	10,416	10,716	500	800	7,416	7,716
Atmospheric Transport Parameter												
Meteorological STAR file	WA_YAKIMA.str				WA_YAKIMA.str				WA_YAKIMA.str			
Groundwater Transport Parameter												
Distance to well (parallel to aquifer flow (m)	12,000				9,000				6,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	12,416				9,416				6,416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	0				315				0			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Yakima TC does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Yakima Training Center Range 14	0.060	0.020
Yakima Training Center Range 17	0.060	0.022
Yakima Training Center Range 20	0.060	0.026

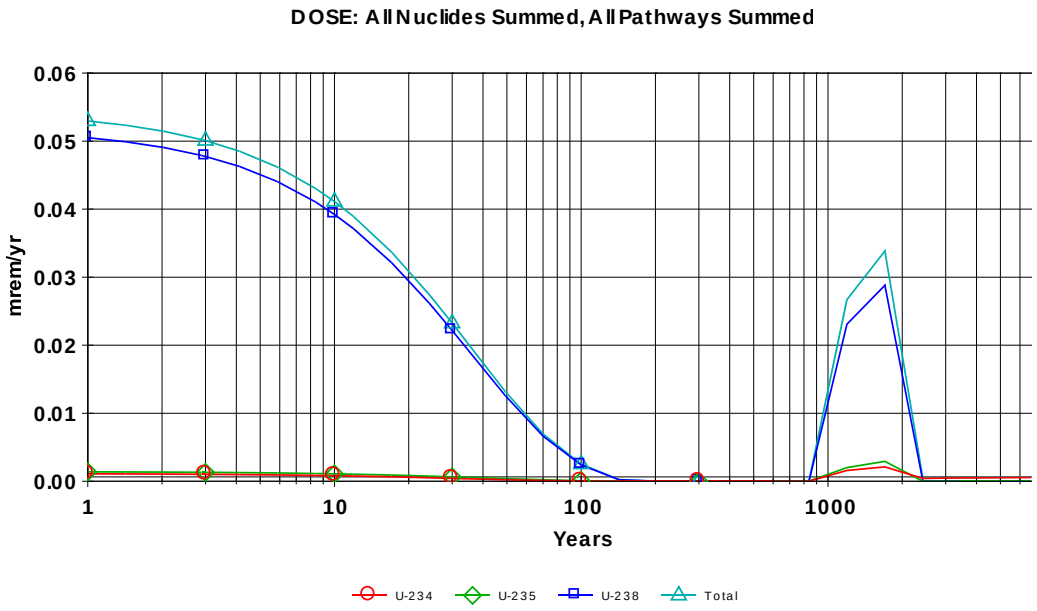
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

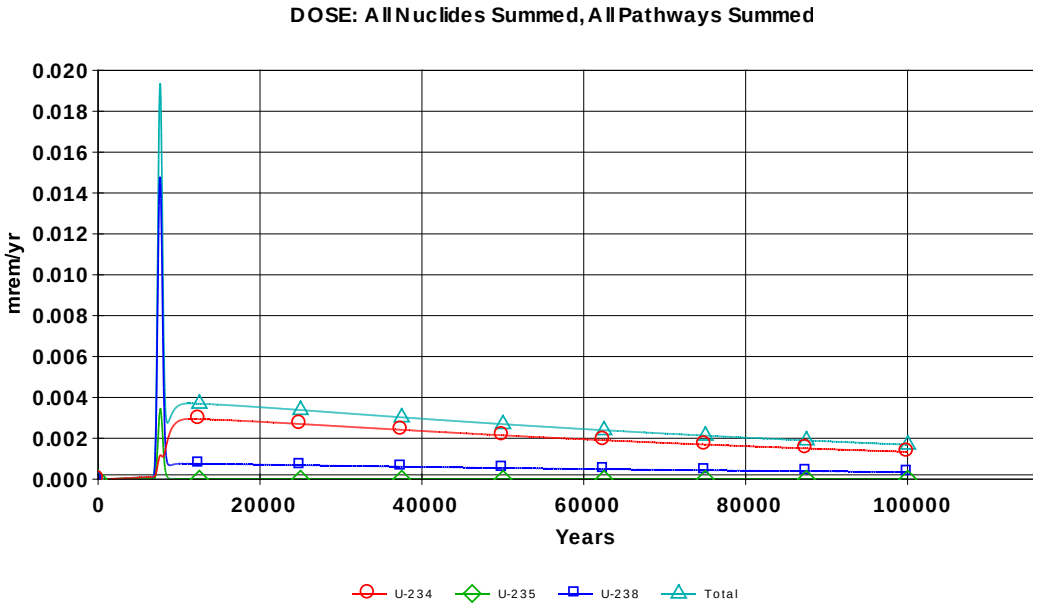
Figure 4-1. Residential Farmer Receptor Dose Graphs

Yakima Training Center Range 14

RCA Onsite (RESRAD)

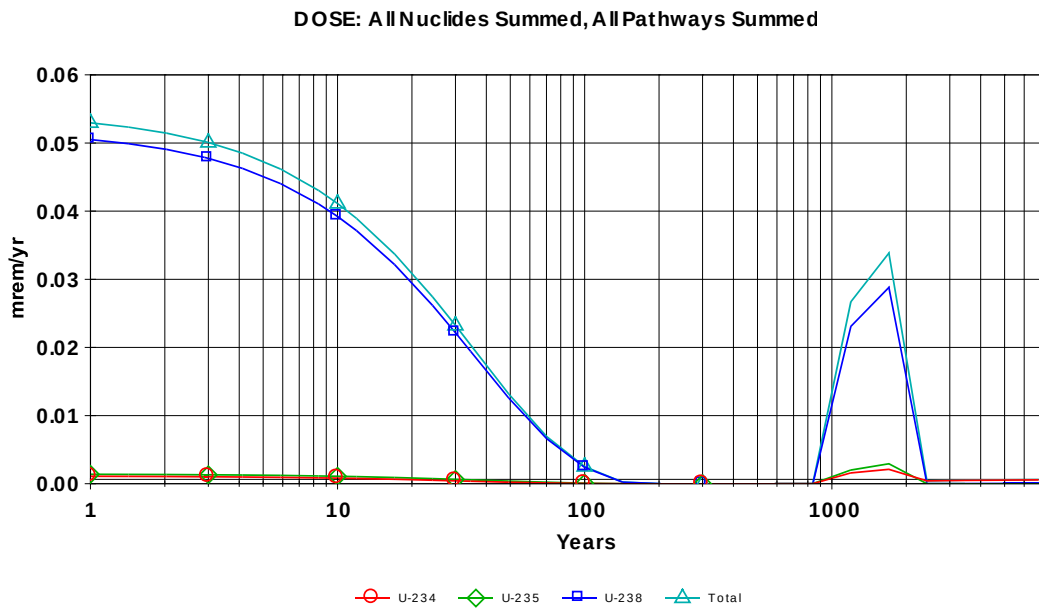


RCA Offsite (RESRAD-OFFSITE)

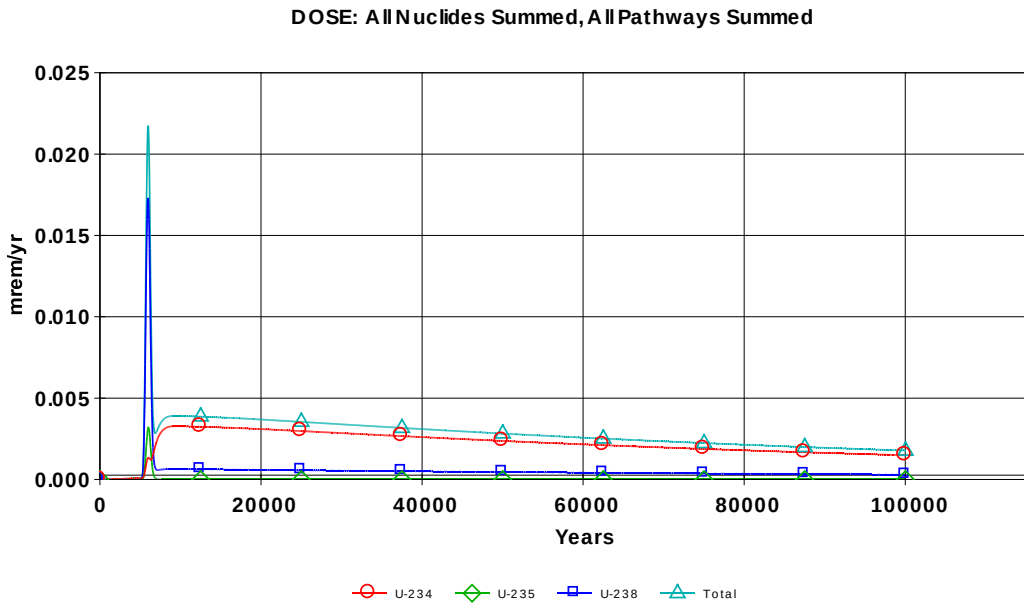


Yakima Training Center Range 17

RCA Onsite (RESRAD)

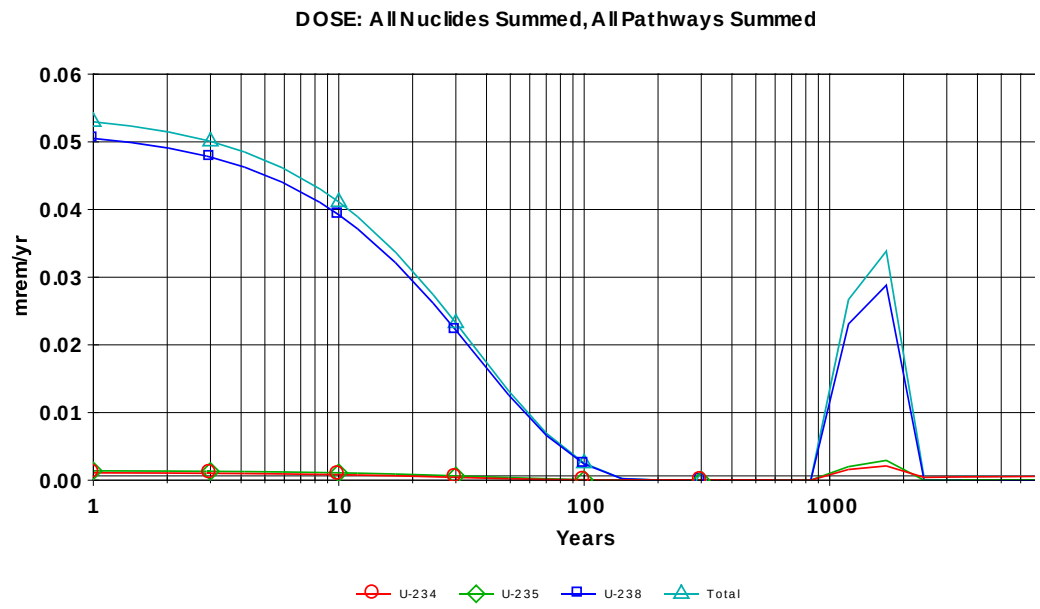


RCA Offsite (RESRAD-OFFSITE)

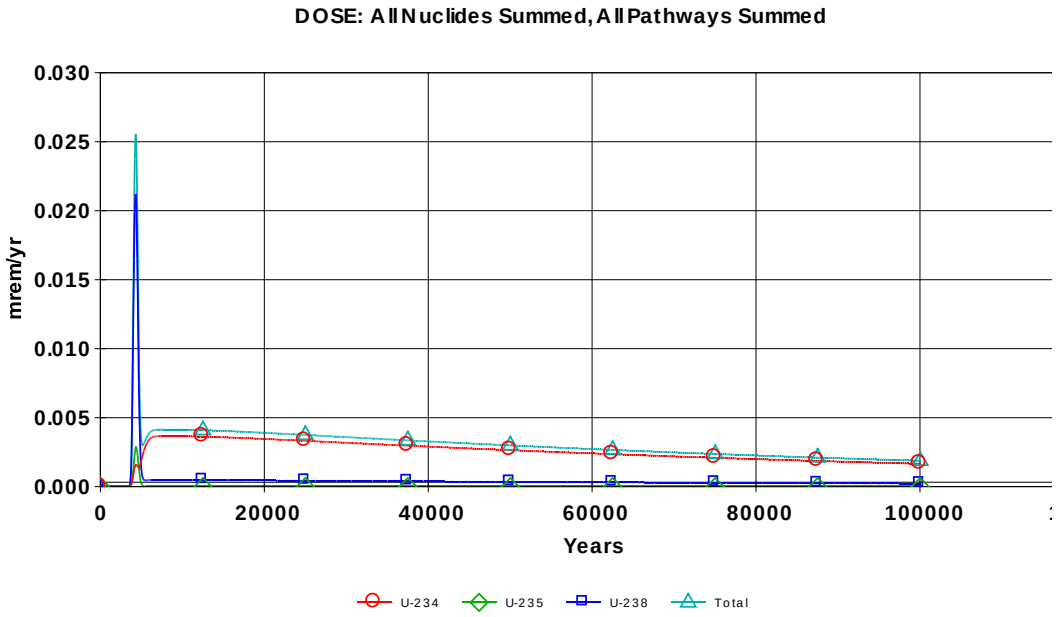


Yakima Training Center Range 20

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



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Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN FORT DIX, JOINT BASE MCGUIRE-DIX-LAKEHURST, NEW JERSEY ANNEX 16

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

U.S. ARMY INSTALLATION MANAGEMENT COMMAND
ATTN: IMSO, Building 2261
2405 Gun Shed Road, Fort Sam Houston, Texas 78234-1223

Submitted To:

U.S. NUCLEAR REGULATORY COMMISSION
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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
BRAC	Base Realignment and Closure Act
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
ft^2/day	Square Feet per Day
FORSCOM	Forces Command
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
JBMDL	Joint Base McGuire-Dix-Lakehurst
kg	Kilogram
m^2	Square Meters
mrem/y	Millirem per Year
msl	Mean Sea Level
mSv/y	MilliSievert per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Fort Dix in Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for JBMDL, New Jersey, Annex 16 (ML16265A230) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Fort Dix. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Two co-located surface water and sediment samples downstream (**SWS-13** and **SWS-14**) from the Frankford Arsenal Range RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., frozen stream)

1.2 INSTALLATION BACKGROUND

Fort Dix is currently the largest military installation in the northeastern United States. It covers 55 square miles in central New Jersey and is located 47 miles east of Philadelphia, Pennsylvania, and 17 miles southeast of Trenton, New Jersey (Figure 1-1).

Fort Dix currently consists of 31,065 acres of land, of which 13,765 acres are range and impact areas and 14,000 are classified as contiguous maneuver areas. The remainder of the installation is the cantonment area. The Fort Dix training areas are bordered by the Lebanon State Forest, Lakehurst Naval Air Engineering Center, and selected Wildlife Management Areas that enable this installation to simultaneously support combat, combat support, and combat service support training. McGuire Air Force Base is on the western edge of Fort Dix, and the Lakehurst Naval Air Engineering Station is on the eastern edge.

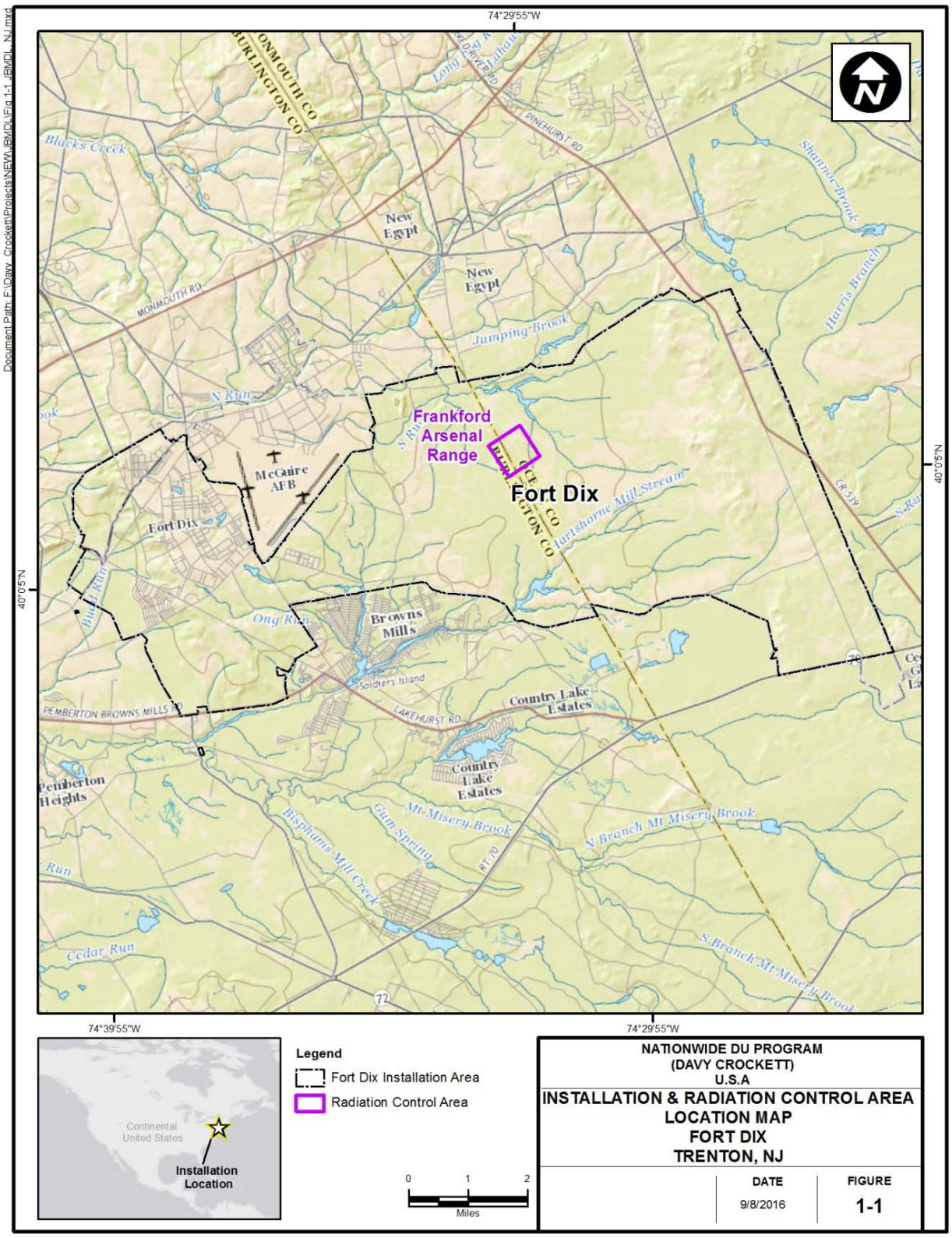

Figure 1-1. Installation and Radiation Control Area Location Map

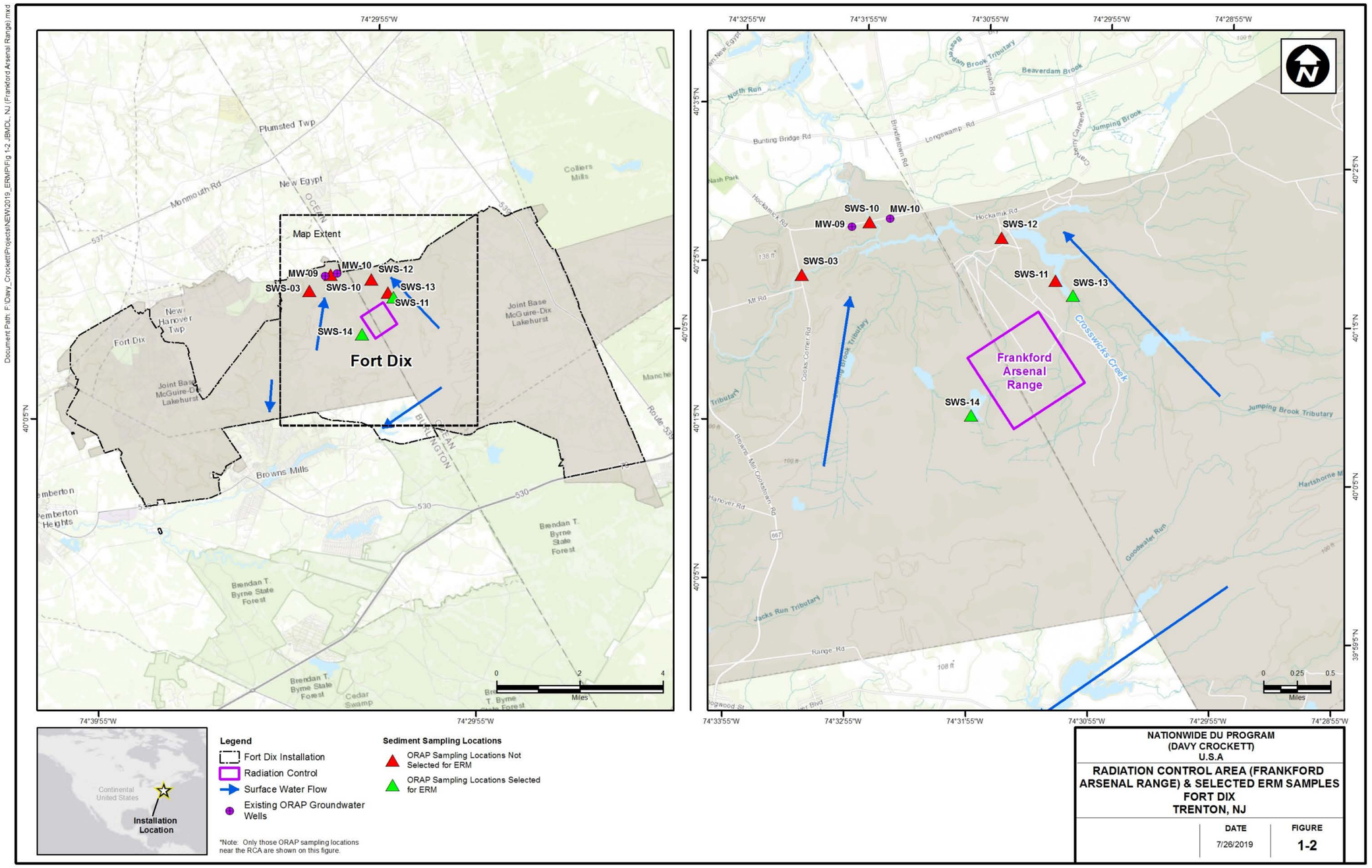

Figure 1-2. Radiation Control Area (Frankford Arsenal Range) and Selected ERM Samples

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Fort Dix has a long and distinguished history. Construction of Camp Dix began in June 1917 and was used as a training and staging center for units during World War I. Following the end of World War I, the camp was designated as a demobilization center. Prior to World War II, on March 8, 1939, the post became Fort Dix, a permanent U.S. Army installation.

Fort Dix has completed its realignment from an individual training center to a Forces Command (FORSCOM) Power Projection Platform for the northeastern United States under the command and control of the U.S. Army Reserve Command. Primary missions include being a center of excellence for training, mobilizing, and deploying Army Reserve and National Guard units, and providing regional base operations support to on-post and off-post active and reserve component units of all services.

In 2005, the U.S. Department of Defense (DoD) announced that Fort Dix would be affected by a Base Realignment and Closure Act (BRAC) action. It was merged with two neighboring military bases, McGuire Air Force Base and Naval Air Engineering Station Lakehurst, establishing JBMDL, New Jersey. There are currently 140 operational ranges at JBMDL totaling approximately 28,000 acres (EA 2012).

An Archives Search Report (ASR) (USACE 2009) confirmed the presence of one range where the Davy Crockett weapons system was used at Fort Dix. The historical Davy Crockett impact area or radiation control area (RCA) consists of 247.5 acres and was known as the Frankford Arsenal Range (Figure 1-2). While there are Dudded Impact Areas to the southeast of the Frankford Arsenal Range, the Operational Range Assessment Program (ORAP) Phase II report designates the Frankford Arsenal Range as a live-fire range surrounded by Non-Dudded Impact Areas (EA 2012). The nearest normally occupied areas to the Frankford Arsenal Range is located approximately 1.7 miles northwest of the RCA.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), JBMDL (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the JBMDL; therefore, it is assumed that most, if not all, of the 10 kilograms (kg) of DU from the rounds fired remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

JBMDL lies within the northern Atlantic Coastal Plain, which is characterized by generally flat to very gently rolling topography. The maximum topographic relief is approximately 130 feet, varying from above 200 feet above mean sea level (msl) in the northwest to 70 feet above msl in the southeast. The TA, ranges on the western portion of the installation, and the impact area are generally flat with elevations varying between 80 and 100 feet above msl (EA 2012).

The headwaters of four watersheds (Toms River, Assiscunk Creek, Rancocas Creek, and Crosswicks Creek) originate on JBMDL. The streams that exit JBMDL have the following designated uses: maintenance, migration, and propagation of natural and established biota; primary and secondary contact

for recreation; industrial and agricultural water supply; public potable water supply after conventional filtration treatment and disinfection; and any other reasonable uses.

Crosswicks Creek drains 11,400 acres of the northern portion of the Fort Dix cantonment area and range complex, including the northern half of the impact area and ranges where small-, medium-, and large-caliber munitions are fired. Crosswicks Creek flows into Brindle Lake along the northern installation boundary. Frankford Arsenal Range is located to the west and near Brindle Lake. After exiting Brindle Lake, Crosswicks Creek flows onto private forestlands and then into a series of active commercial cranberry bogs. Crosswicks Creek continues north of JBMDL for approximately 6 miles before turning west toward the Delaware River.

The southeastern area of the RCA in Fort Dix is drained to the northeast into Brindle Lake via a small stream (Figure 1-2). The western central portion of the RCA is drained by another small stream that exits the RCA to the west for a short distance before entering a cranberry bog.

Groundwater occurs within the northern Pinelands Section of the New Jersey Coastal Plain. Groundwater yield within the area is known to vary considerably depending on formation. Six major aquifers have been identified in the Coastal Plain: the Kirkwood-Cohansey aquifer (the upper water-bearing unit at JBMDL), Lower Member of the Kirkwood, Mount Laurel-Wenonah, Marshalltown-Wenonah, Englishtown, and Potomac-Raritan-Magothy. Due to the confining units separating the aquifers, water does not tend to move from one aquifer to another.

The depth to groundwater in the Kirkwood-Cohansey aquifer is less than 5 feet below ground surface (bgs) and groundwater flow generally follows topography. The recharge area of the Kirkwood-Cohansey aquifer system covers 2,250 square miles and matches the dimensions of the Cohansey Sand formation. Recharge of the Cohansey and Kirkwood formations is primarily by precipitation falling on exposed portions of the units. Transmissivity rates of the Kirkwood-Cohansey aquifer range from approximately 3,102 to 38,475 square feet per day (ft^2/day), and vertical hydraulic conductivity rates range from 36 to 420 feet per day, according to the New Jersey Geologic Survey. The Kirkwood-Cohansey aquifer also recharges surface water. Approximately 90 percent of stream flow in the area of JBMDL is from shallow groundwater discharges of the Kirkwood-Cohansey aquifer system (New Jersey Geological Survey 2009).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the Frankford Arsenal Range at Fort Dix are as follows:

- ***Surface Water Use***—Surface water in the vicinity of JBMDL is used for drinking water. Approximately 80 percent of the water used at JBMDL is obtained from a surface water intake along the Greenwood Branch of Rancocas Creek. Frankford Arsenal Range does not drain into Rancocas Creek.
- ***Recreational Use***—Local off-range surface water bodies within 15 miles are used for recreational purposes.
- ***Sensitive Environments***—JBMDL is located within the New Jersey Pinelands, which is the largest area of contiguous, undeveloped forest and wetland on the Atlantic Coastal Plain of the Mid-Atlantic region. The mosaic of globally rare upland and wetland communities and species found here is of national significance and the New Jersey Pinelands is the largest pine barrens complex in the world. The Pinelands overlay one of the largest aquifers in the country, and the wetlands and pristine headwaters arising within the Pinelands support a unique assemblage of

indigenous species and are critical for the water quality and productivity of the New Jersey backbarrier lagoon estuaries (USFWS 2016).

- ***Habitat***—JBMDL is located at the northern end of the New Jersey Pinelands and can be provisionally divided into three forest communities: pine-oak, oak-hickory, and white cedar-type forests. The base contains approximately 24,200 wooded acres; 14,000 acres deemed commercial forest; and 10,200 acres for impact use.
- ***Ecological Receptors***—There are 223 species of special emphasis in the New Jersey Pinelands, incorporating 84 species of plants and 75 species of birds (USFWS 2016).
- ***Groundwater Use***—Groundwater in the vicinity of JBMDL is used for drinking water. Public groundwater supply wells have been identified in the Crosswicks Creek watershed. The bulk of these wells are screened in deep, confined aquifers that are not likely to be impacted by activities directly linked to the water table.

Potential human receptors include those within Fort Dix and off-range relying on surface water downgradient from the RCA for potable water. Ecological receptors include sensitive environments (e.g., wetlands) and species of special emphasis in the New Jersey Pinelands potentially present at Fort Dix.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Frankford Arsenal Range at Fort Dix are discussed in the following sections.

Very limited sampling is recommended for the RCA. While a few ORAP Phase II samples have been collected downstream from the Frankford Arsenal Range (EA 2012), they were not analyzed for total/isotopic uranium and their placement was used to determine the presence/absence of munitions constituents other than DU. The ORAP Phase II assessment does not specify why total/isotopic uranium was not part of the analytical suite. However, it should be noted that there was limited usage of DU at the Frankford Arsenal Range. No units were authorized to field the Davy Crockett Weapon System at Fort Dix during the Davy Crockett M28 era (1958-1968). Less than 50 Cartridges, 20mm Spotting M101 were fired at Fort Dix. While the amount of additional XM101 20mm cartridges potentially fired at Fort Dix could not be determined, minimal Davy Crockett weapon and/or M101/XM101 20mm spotting rounds debris is expected to be found on the Frankford Arsenal Range at Fort Dix. This was confirmed during a range inspection in 2009 when no Davy Crockett weapon or ammunition debris was found.

2.1 SURFACE WATER AND SEDIMENT

The surface water and sediment sampling approach will involve the collection of two samples from locations downstream from the RCA in Fort Dix (Figure 1-2) where surface water flows throughout the year. If surface water is not flowing when a semiannual sampling event is planned (e.g., frozen stream, dry stream) or when sampling is too dangerous (e.g., rapid flow during flooding), no surface water samples will be collected during that event. Sediment samples will be collected on a semiannual basis unless sediment is inaccessible when a semiannual sampling event is planned (e.g., frozen stream, flooding). The surface water and sediment sampling locations at Fort Dix were selected based on the surface water hydrology and potential for DU contribution and are located as follows:

- ***SWS-13***—The selected sampling point is located just upstream of Brindle Lake on a stream that drains the southeastern portion of the RCA. SWS-13 is downstream from the northeastern boundary of the RCA.
- ***SWS-14***—The selected sampling point is located just outside the western boundary of the RCA on a stream that drains the west-central portion of the RCA.

Historical surface water and sediment sample locations SWS-03, SWS-10, SWS-11, and SWS-12 will not be sampled during the environmental radiation monitoring (ERM). The proposed ERM is focused on surface water features downstream of the Frankford Arsenal Range and locations SWS-03, SWS-10, SWS-11, and SWS-12 are located on surface water features inapplicable to the RCA. In addition, the historical samples were not analyzed for total and isotopic uranium during the ORAP Phase II assessment (EA 2012).

Surface water and sediment samples will be analyzed for total/isotopic uranium using the U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry).

Further details on analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional surface water and sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for JBMDL, New Jersey, Annex 15 (ML16265A230) (U.S. Army 2016), the Army conducted quarterly surface water and sediment sampling at the selected downstream sampling locations, SWS-13 and SWS-14, in 2017 and 2018. The concentrations of total and isotopic uranium in surface water and sediment from the ERM sampling events at JBMDL are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-13	6/5/2017	0.95 +/- 0.76
SWS-14	6/5/2017	ND
SWS-13	8/22/2017	ND
SWS-14	8/22/2017	ND
SWS-13	11/21/2017	ND
SWS-14	11/21/2017	ND
SWS-13	3/6/2018	ND
SWS-14	3/6/2018	ND
SWS-13	6/5/2018	1.0 +/- 1
SWS-14	6/5/2018	ND
SWS-13	9/6/2018	0.2 +/- 0.19
SWS-14	9/6/2018	ND
SWS-13	11/27/2018	ND
SWS-14	11/27/2018	ND

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).
+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).
ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 and 2-2, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at JBMDL.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-13	6/5/2017	1.9 +/- 0.7
SWS-14	6/5/2017	1.3 +/- 1
SWS-13	8/22/2017	1.1 +/- 0.4
SWS-14	8/22/2017	0.60 +/- 0.3
SWS-13	11/21/2017	1.5 +/- 0.5
SWS-14	11/21/2017	0.77 +/- 0.58
SWS-13	3/6/2018	1.2 +/- 0.9
SWS-14	3/6/2018	0.41 +/- 0.29
SWS-13	6/5/2018	1.3 +/- 0.5
SWS-14	6/5/2018	0.79 +/- 0.47
SWS-13	9/6/2018	1.8 +/- 0.7
SWS-14	9/6/2018	0.81 +/- 0.49
SWS-13	11/27/2018	0.81 +/- 0.51
SWS-14	11/27/2018	0.49 +/- 0.32

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

2.2 GROUNDWATER

Presently, no ORAP groundwater monitoring wells are located at or near the RCA and the groundwater samples collected as part of the ORAP Phase II assessment were not analyzed for total and isotopic uranium. As noted previously, the Kirkwood-Cohansey aquifer is the upper water-bearing unit at JBMDL, which is less than 5 feet bgs, and also recharges surface water. Approximately 90 percent of stream flow in the area of JBMDL is from shallow groundwater discharges of the Kirkwood-Cohansey aquifer system (New Jersey Geological Survey 2009). As a result, the surface water and sediment sampling downstream from the RCA would have covered both direct migration from overland flow into streams and migration from groundwater to surface water. For this reason and additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for JBMDL.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of environmental radiation samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Fort Dix does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to JBMDL will be coordinated with the JBMDL Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 mass to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

A grab surface water sample will be collected using disposable equipment (e.g., tubing) or collected directly into sample containers. Details of the surface water sampling and the associated field procedures are provided in Annex 19.

Sampling activities, including documentation of the site conditions and the sample details, will be included within the field logbook. Following the sampling, each location will be surveyed with a differential global positioning system (DGPS) unit to identify the location with sub-meter accuracy and documented in the field logbook. Digital photographs will be taken during the sampling.

Once the sample is collected, the sample and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected in the shallow surface water locations using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow

is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a DGPS unit.
9. Collect digital photographs and document data in the field logbook.

Additional details on the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on the RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (10 kg) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Joint Base McGuire-Dix-Lakehurst RCA

Parameter		Default Value	Frankford Arsenal Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	9.84×10^{-4}	Site-specific calculation based on the DU mass listed in the NRC SML = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	9.01×10^{-5}	
	U-238	N/A	0.01	
Area of contaminated zone (m^2)		10,000	1,000,000	One square kilometer
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 5ft bgs
Length parallel to aquifer flow (m)		100	1,000	Length of RCA is approximately 1,000 m
Contaminated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand (Soil is clayey course sand)
Contaminated zone hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	8.9	www.usa.com for Fort Dix, NJ
Precipitation rate (annual rainfall) (m/y)		1.0	1.2	www.usa.com for Fort Dix, NJ
Saturated Zone				
Saturated zone total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone				
Unsaturated zone 1, thickness (m)		4.0	1.5	Depth to groundwater is generally 5ft.
Unsaturated zone 1, total porosity		0.4	0.39	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, effective porosity		0.2	0.3	RESRAD Manual Table E-8 (DOE 2001) for Course Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Joint Base McGuire-Dix-Lakehurst RCA

RCA Layout Parameter	Frankford Arsenal Range			
Distance to nearest normally occupied area (m)	2,700			
Bearing of X axis (degrees)	45 (northwest)			
X dimension of primary contamination (m)	1,000			
Y dimension of primary contamination (m)	1,000			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	3800	3832
Leafy vegetables plot	500	531.25	3834	3866
Pasture, silage growing area	500	600	4016	4116
Grain fields	500	600	3866	3966
Dwelling site	500	531.25	3700	3732
Surface-water body	500	800	4116	4416
Atmospheric Transport Parameter				
Meteorological STAR file	NJ_WRIGHTSTOWN_MCGUI.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	2,700			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	3,116			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	225			

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at JBMDL does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	Onsite[a] (RESRAD)	Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Joint Base McGuire-Dix-Lakehurst Frankford Arsenal Range	1.2×10^{-3}	9.6×10^{-4}

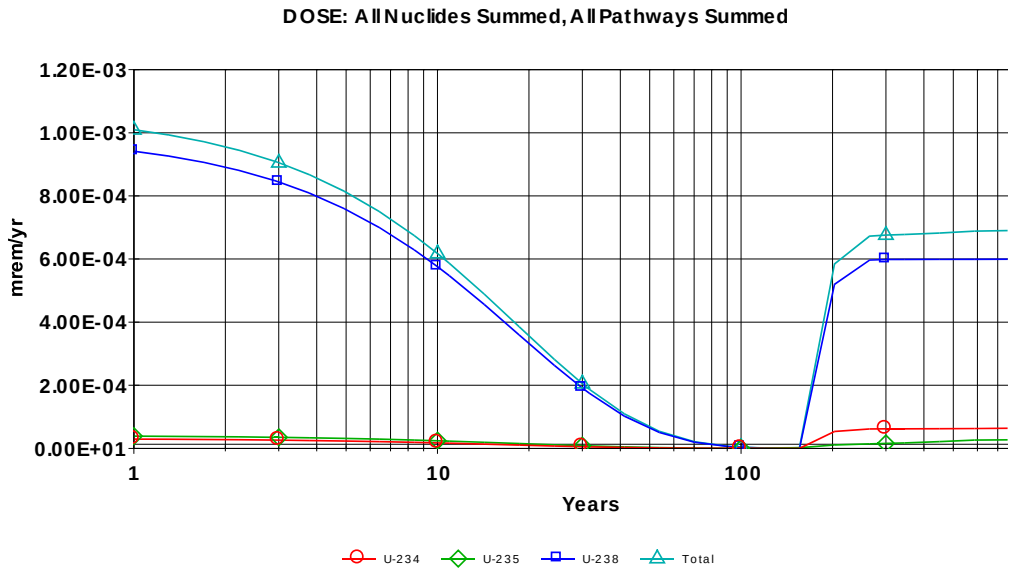
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

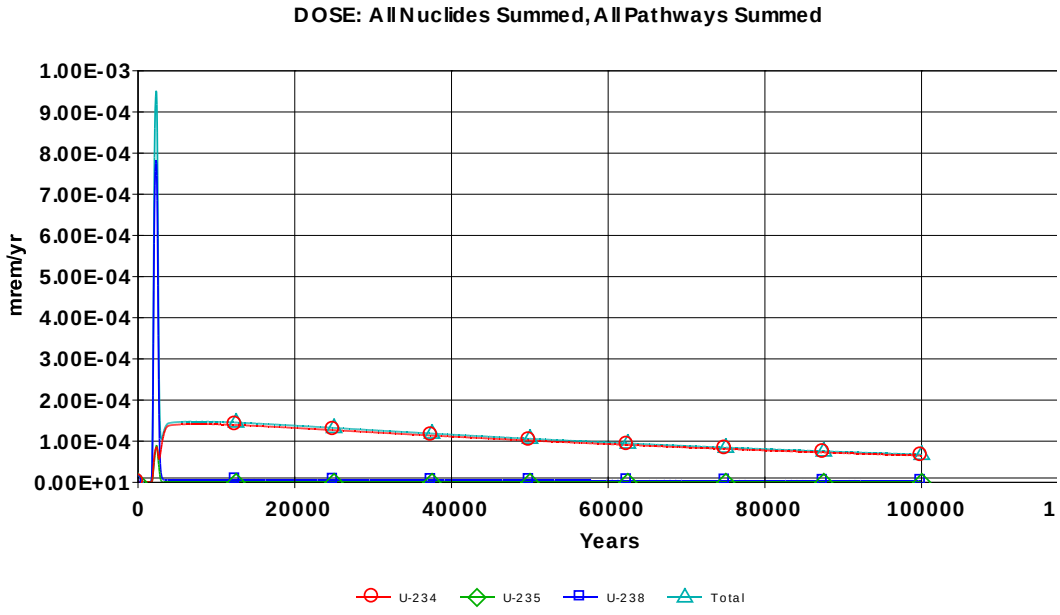
Figure 4-1. Residential Farmer Receptor Dose Graphs

Joint Base McGuire-Dix-Lakehurst Frankford Arsenal Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ + (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ = 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN POHAKULOA TRAINING AREA, HAWAII ANNEX 17

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

Submitted By:

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
bgs	Below Ground Surface
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain-of-Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HARNG	Hawaii Army National Guard
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
kg	Kilogram
m^2	Square Meters
msl	Mean Sea Level
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UXO	Unexploded Ordnance

1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Pohakuloa Training Area (TA) in Hawaii, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for PTA, Hawaii, Annex 17 (ML1718A184) (U.S. Army 2017).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at Pohakuloa TA. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Location

Sample Location	Sample Media	Sample Frequency
One sediment sample downstream (**ERM-01**) from the RCAs, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

Pohakuloa TA is a 131,425-acre installation located on the island of Hawaii, approximately 40 miles west of Hilo and 40 miles east of Kawaihae, Hawaii (Figure 1-1). A public highway, known as Saddle Road, traverses the northern portion of the area and serves as a major land route.

Pohakuloa TA was acquired by the United States from the State of Hawaii and private landowners. The facility is used by the U.S. Army Hawaii, the U.S. Marine Corps, and the Hawaii Army National Guard (HARNG).

Pohakuloa TA consists of a cantonment area, a maneuver area, an impact area, and a safety buffer zone. The cantonment area or Base Camp consists of administrative and logistical buildings, troop billets, Bradshaw Airfield, and the ammunition storage area. The Maneuver Area consists of limited road net and prominent terrain features. The Pohakuloa Impact Area is an area generally bounded on the north by Lava Road, on the east by Redleg Road, on the south by Kona-Hilo Trail, and on the west of Bobcat Trail.

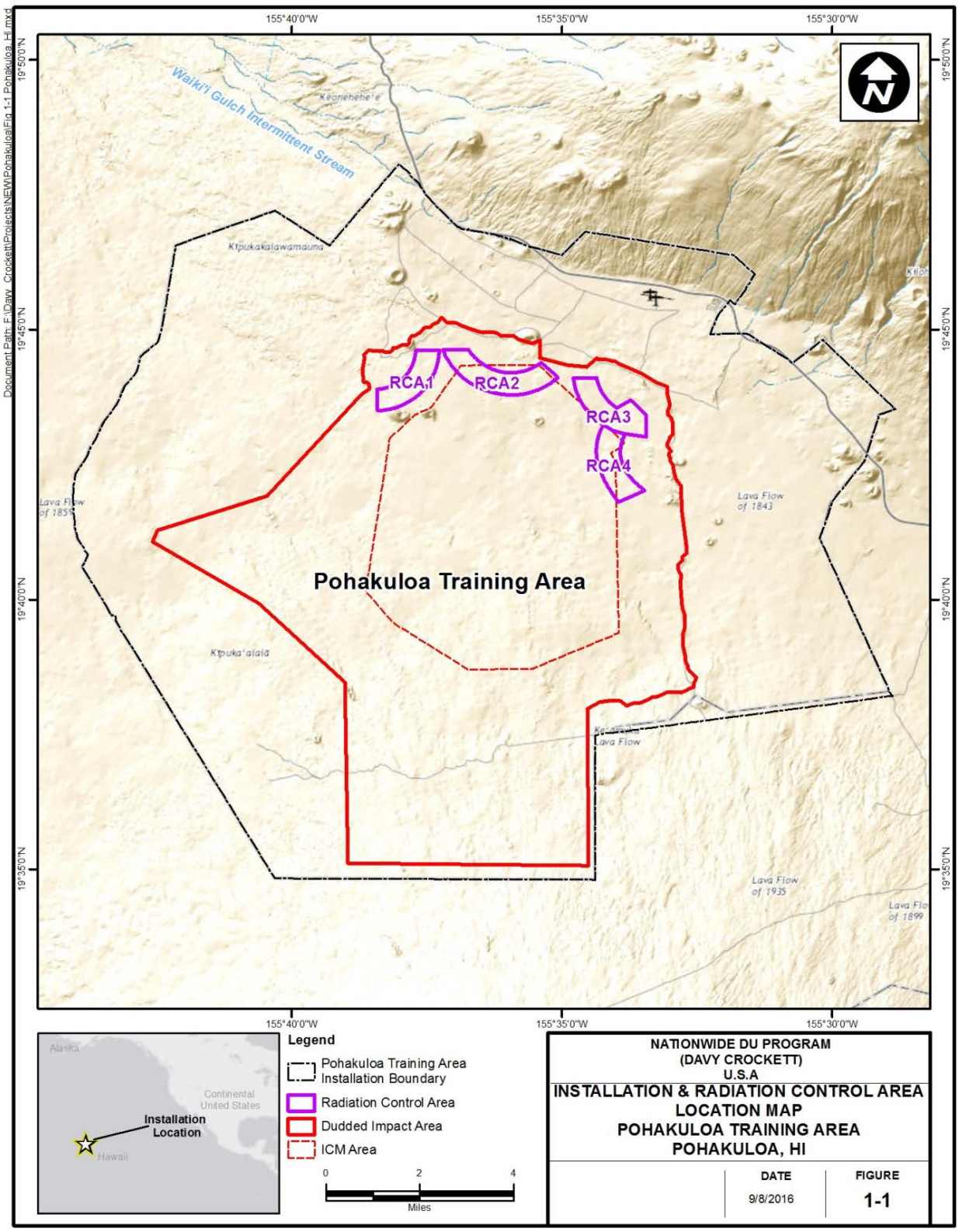

Figure 1-1. Installation and Radiation Control Area Location Map

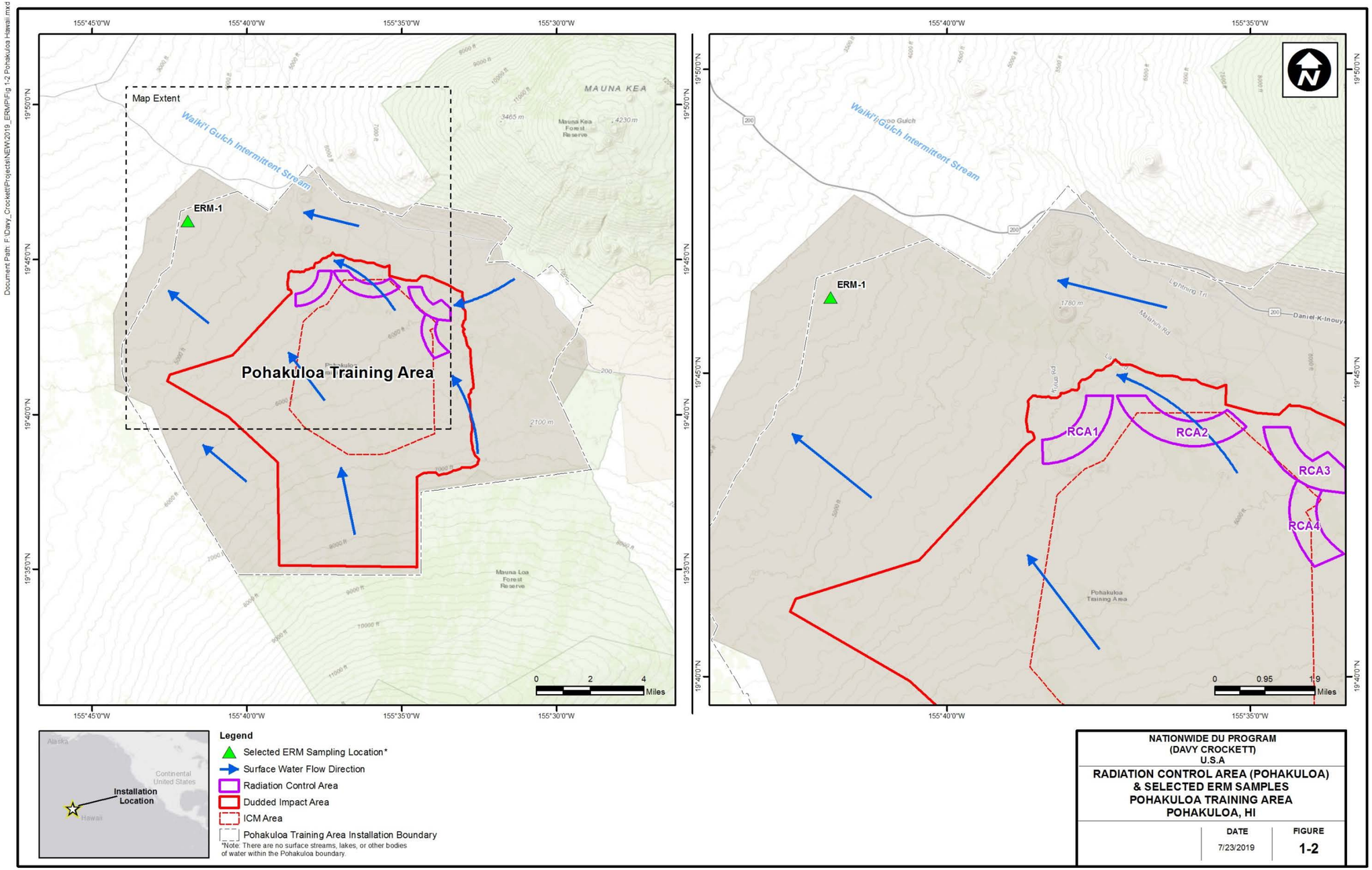

Figure 1-2. Radiation Control Area (Pohakuloa) and Selected ERM Samples

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The Archives Search Report (ASR) (USACE 2007) confirmed the presence of the Davy Crockett Range at Pohakuloa TA based on range type and use, historical range maps, and range regulations and common practice for the time period of the fielded Davy Crockett Weapon System (i.e., 1961 through 1968). The nearest normally occupied areas to the Davy Crockett Ranges or radiation control areas (RCAs) are 16 miles west-northwest.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU, which was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly TA), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the Davy Crockett Ranges; therefore, it is assumed that most, if not all, of the 140 kilograms (kg) of DU from the rounds fired into RCAs at Schofield Barracks and Pohakuloa TA remains in the RCAs.

1.4 PHYSICAL ENVIRONMENT

Pohakuloa TA is in the Humuula Saddle between the two major peaks on the Island of Hawaii; Mauna Kea lies to the northeast and Mauna Loa lies to the south. Elevations within Pohakuloa TA range from 4,030 to 8,650 feet above mean sea level (msl).

Pohakuloa TA lies within the Northwest Mauna Loa and the West Mauna Kea watersheds, which drain to the northern Hualalai and southern Kohala coasts, respectively. There are no surface streams, lakes, or other bodies of water within the Pohakuloa TA boundary due to low rainfall, porous soils, and lava substrates. Rainfall, fog drip, and occasional frost are the main sources of water. Perennial streams are more than 15 miles from Pohakuloa TA on the northeast side of the island.

Rainfall is the primary source of groundwater recharge at Pohakuloa TA, and the geology is characterized by highly permeable lavas from which little or no runoff occurs. Most of the precipitation percolates relatively quickly to the underlying groundwater and then moves seaward, discharging into the coastal waters.

Pohakuloa TA lies above two aquifer systems: the Northwest Mauna Loa and the West Mauna Kea aquifer sectors. The majority of Pohakuloa TA lies within the Northwest Mauna Loa aquifer sector. Based on regional hydrogeological information, it is believed that the groundwater beneath Pohakuloa TA occurs primarily as deep basal water within the older Pleistocene age basalts (U.S. Army 2013).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

Source data were analyzed along with potential migration pathways and potential off-range human and/or ecological receptors. This information was collected for the RCAs and used to determine if a potential source-receptor interaction existed for each relevant pathway identified. Based on this analysis, the source-pathway-receptor interaction was considered unlikely for the Davy Crockett Ranges.

No surface water or groundwater migration pathways were identified. Due to the low mobility of metals in soils and the depth to groundwater (greater than 1,000 feet below ground surface [bgs]), metals were not expected to infiltrate through the soil profile to groundwater. In addition, due to low rainfall, porous soils, and lava substrates, no perennial surface water bodies are located on, or immediately adjacent to, Pohakuloa TA. The closest known surface water body is located 4.5 miles upgradient of Pohakuloa TA. There are no perennial streams within 15 miles of Pohakuloa TA, but there are intermittent streams located northeast of Pohakuloa TA and only one intermittent stream, Popoo Gulch, drains the northern portion of Pohakuloa TA. Despite occasional flow, water in the intermittent stream channels infiltrates rapidly once precipitation stops and the streams become dry (EA 2013).

2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCAs or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the Davy Crockett Ranges at Pohakuloa TA are discussed in the following sections.

2.1 SEDIMENT

There are no surface water features (i.e., streams, lakes, or other bodies of water) within the Pohakuloa TA boundary, and intermittent streams flow only following heavy rainfall and dry up quickly; therefore, sampling is restricted to sediment collection only. The sediment sampling approach will involve the collection of sediment samples from a location downstream from the RCAs in Pohakuloa TA (Figure 1-2). The sediment sampling location at Pohakuloa TA was selected based on the surface water hydrology and potential for DU contribution and is located as follows:

- ***ERM-01***—The selected sampling point is located at an intermittent stream at the installation's northern boundary, downstream from the RCAs. ERM-01 is accessible using the Lightning Trail or via Saddle Road.

Sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional sediment samples within 30 days of the notification to NRC. The sediment samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

In accordance with the Site-Specific ERMP for PTA, Hawaii, Annex 17 (ML1718A184) (U.S. Army 2017), the Army conducted quarterly sediment sampling at the selected sampling location, ERM-01, in 2017 and 2018. The concentrations of total and isotopic uranium in sediment from the environmental radiation monitoring (ERM) sampling events at PTA are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Table 2-1.

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Table 2-1, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in sediment at Pohakuloa TA.

Table 2-1. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
ERM-01	6/14/2017	0.39 +/- 0.27
ERM-01	9/6/2017	0.70 +/- 0.34
ERM-01	11/28/2017	1.1 +/- 0.6
ERM-01	2/20/2018	1.3 +/- 0.6
ERM-01	6/20/2018	0.64 +/- 0.3
ERM-01	9/10/2018	0.83 +/- 0.35
ERM-01	12/13/2018	0.61 +/- 0.29

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

2.2 GROUNDWATER

Presently, no groundwater monitoring wells are located at or near the RCAs. The depth to groundwater in the vicinity of Pohakuloa TA is approximately 1,000 feet bgs. Although the area within the vicinity of Pohakuloa TA exhibits high soil permeability, the combination of limited precipitation and great depth to groundwater make it unlikely that DU would migrate into the groundwater. For these reasons and the additional rationale included in the PAERMP (U.S. Army 2019), groundwater sampling is not planned for Pohakuloa TA.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of ERM samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, Pohakuloa TA does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2019).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to Pohakuloa TA will be coordinated with the Pohakuloa TA Installation Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

No surface water samples will be collected because of the lack of surface water features (i.e., streams, lakes, or other bodies of water) due to low rainfall, porous soils, and lava substrates within Pohakuloa TA.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected from the stream bed using a clean, disposable plastic scoop. Sampling locations within the stream bed should be selected where the intermittent surface water flow is low and/or deposition is most likely. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.

6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.
7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a differential global positioning system (DGPS) unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the selected laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (140 kg for Schofield Barracks and Pohakuloa TA) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Pohakuloa Training Area RCAs

Parameter		Default Value	Area 1	Area 2	Area 3	Area 4	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	FGR 11 & 12	FGR 11 & 12	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone							
Soil concentrations (pCi/g)	U-234	N/A	1.38×10^{-2}	1.38×10^{-2}	1.38×10^{-2}	9.19×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML (NRC 2016). = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	1.26×10^{-3}	1.26×10^{-3}	1.26×10^{-3}	8.41×10^{-4}	
	U-238	N/A	0.21	0.21	0.21	0.14	
Area of contaminated zone (m^2)		10,000	1,000,000	1,000,000	1,000,000	1,500,000	Area of RCA
Depth of contaminated zone (m)		2	0.15	0.15	0.15	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	0	0	0	Depth to groundwater is approximately 1,000 ft bgs
Length parallel to aquifer flow (m)		100	1,000	1,000	1,000	1,500	Groundwater flows northeast across RCA
Contaminated zone total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Contaminated zone hydraulic conductivity (m/y)		10	4,930	4,930	4,930	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Contaminated zone b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Average annual wind speed (m/s)		2.0	5.3	5.3	5.3	5.3	U.S. Army 2013
Precipitation rate (annual rainfall) (m/y)		1.0	0.51	0.51	0.51	0.51	U.S. Army 2013
Saturated Zone							
Saturated zone total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Saturated zone effective porosity		0.2	0.33	0.33	0.33	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Saturated zone hydraulic conductivity (m/y)		100	4,930	4,930	4,930	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Saturated zone b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated Zone							
Unsaturated zone 1, total porosity		0.4	0.43	0.43	0.43	0.43	RESRAD Manual Table E.8 (DOE 2001) for Fine Sand
Unsaturated zone 1, effective porosity		0.2	0.33	0.33	0.33	0.33	RESRAD Manual Table E-8 (DOE 2001) for Fine Sand
Unsaturated zone 1, soil-specific b parameter		5.3	4.38	4.38	4.38	4.38	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand
Unsaturated zone 1, hydraulic conductivity (m/y)		10	4,930	4,930	4,930	4,930	RESRAD Manual Table E.2 (DOE 2001) for Loamy Sand

* See Table 4-1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters Pohakuloa Training Area RCAs

RCA Layout Parameter	Area 1				Area 2				Area 3				Area 4			
Distance to nearest normally occupied area (m)	4,900				3,400				4,400				6,000			
Bearing of X axis (degrees)	135 (northeast)				135 (northeast)				135 (northeast)				135 (northeast)			
X dimension of primary contamination (m)	1,000				1,000				1,000				1,000			
Y dimension of primary contamination (m)	1,000				1,000				1,000				1,500			
Location	X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)		X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	6,000	6,032	500	531.25	4,500	4,532	500	531.25	5,500	5,532	500	531.25	7,600	7,632
Leafy vegetables plot	500	531.25	6,034	6,066	500	531.25	4,534	4,566	500	531.25	5,534	5,566	500	531.25	7,634	7,666
Pasture, silage growing area	500	600	6,216	6,316	500	600	4,716	4,816	500	600	5,716	5,816	500	600	7,816	7,916
Grain fields	500	600	6,066	6,166	500	600	4,566	4,666	500	600	5,566	5,666	500	600	7,666	7,766
Dwelling site	500	531.25	5,900	5,932	500	531.25	4,400	4,432	500	531.25	5,400	5,432	500	531.25	7,500	7,532
Surface-water body	500	800	6,316	6,616	500	800	4,816	5,116	500	800	5,816	6,116	500	800	7,916	8,216
Atmospheric Transport Parameter																
Meteorological STAR file*	CA_SAN_DIEGO.str				CA_SAN_DIEGO.str				CA_SAN_DIEGO.str				CA_SAN_DIEGO.str			
Groundwater Transport Parameter																
Distance to well (parallel to aquifer flow) (m)	4,900				3,400				4,400				6,000			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	5,316				3,816				4,816				6,416			
Distance to well (perpendicular to aquifer flow) (m)	0				0				0				0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150				-150				-150				-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150				150				150				150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315				315				315				315			

* RESRAD Offsite has no meteorological STAR files for Alaska or Hawaii. The selected STAR file is based on nearest available location. The inhalation pathway dose is insignificant to external and groundwater dose pathways.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for each RCA evaluated at Pohakuloa TA does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Davy Crockett Range Area 1	0.025	0.012
Davy Crockett Range Area 2	0.025	0.013
Davy Crockett Range Area 3	0.025	0.012
Davy Crockett Range Area 4	0.017	0.0074

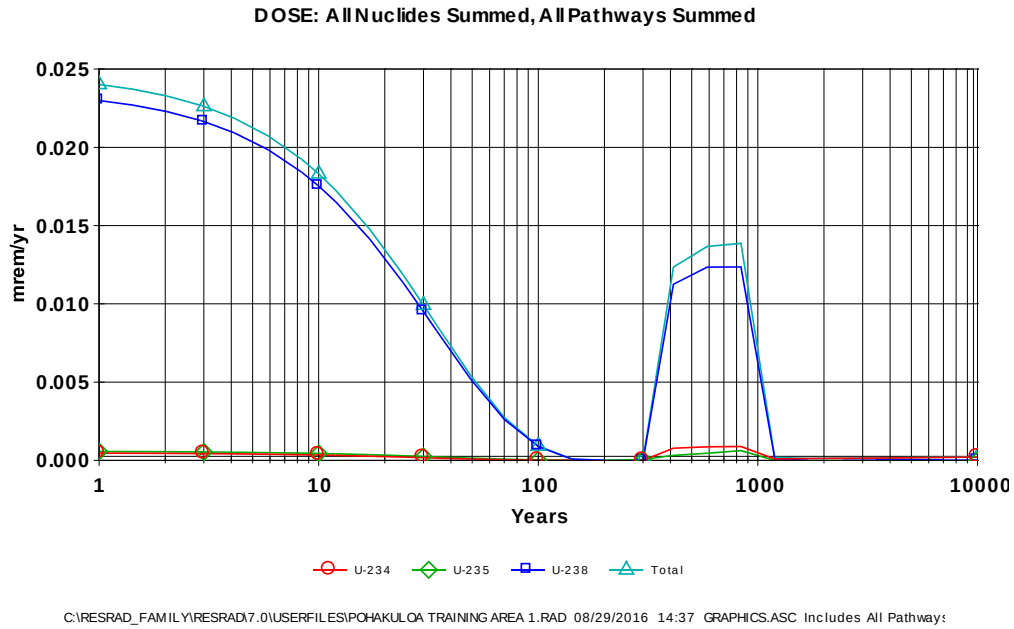
[a] The onsite residential farmer receptor resides on the RCA.
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

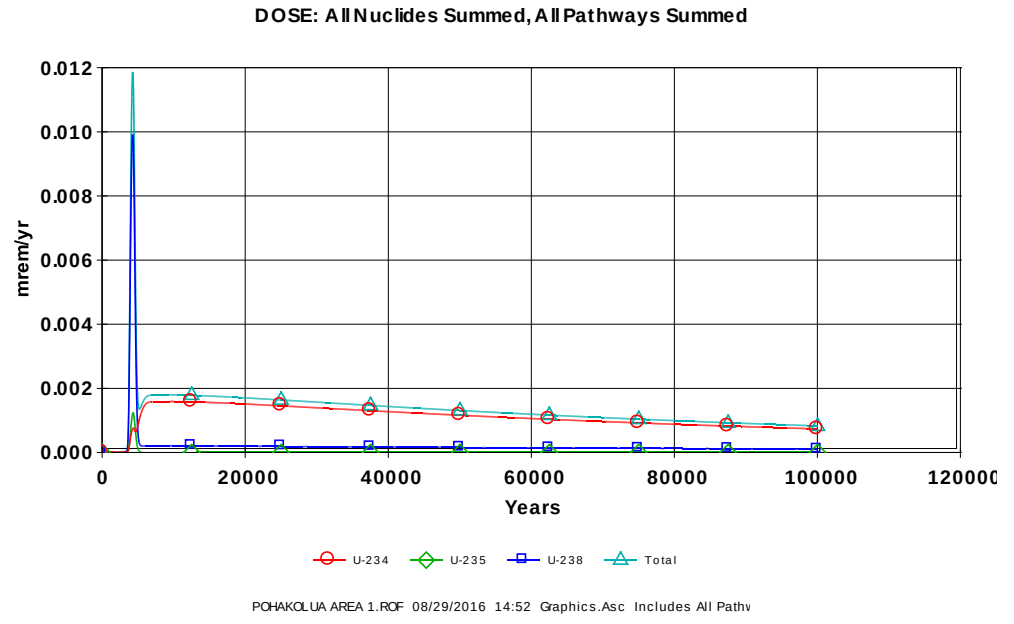
Figure 4-1. Residential Farmer Receptor Dose Graphs for Pohakuloa Training Area RCAs

Davy Crockett Range Area 1

RCA Onsite (RESRAD)

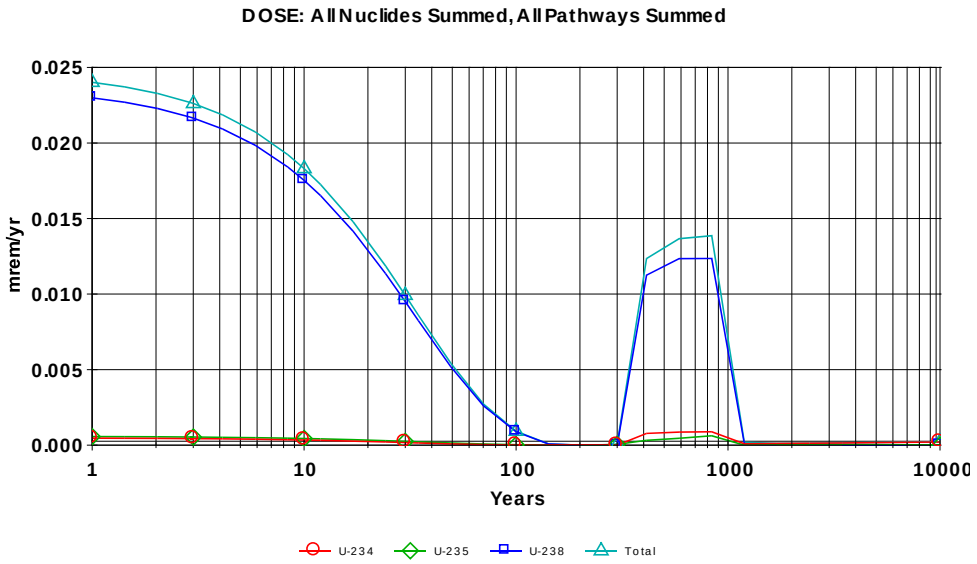


RCA Offsite (RESRAD-OFFSITE)

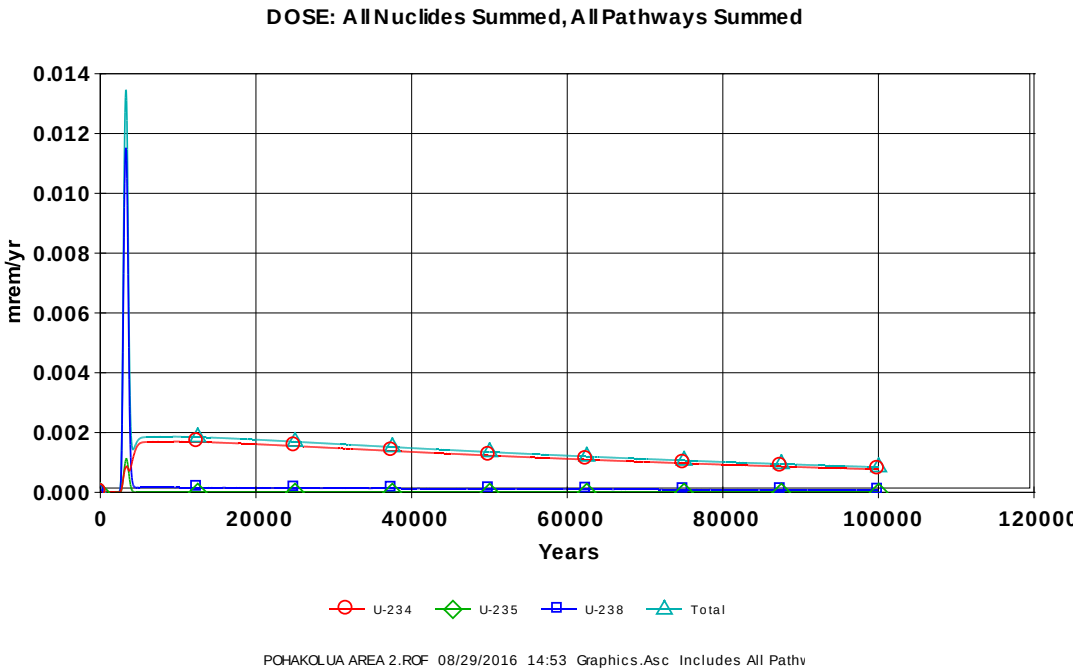


Davy Crockett Range Area 2

RCA Onsite (RESRAD)

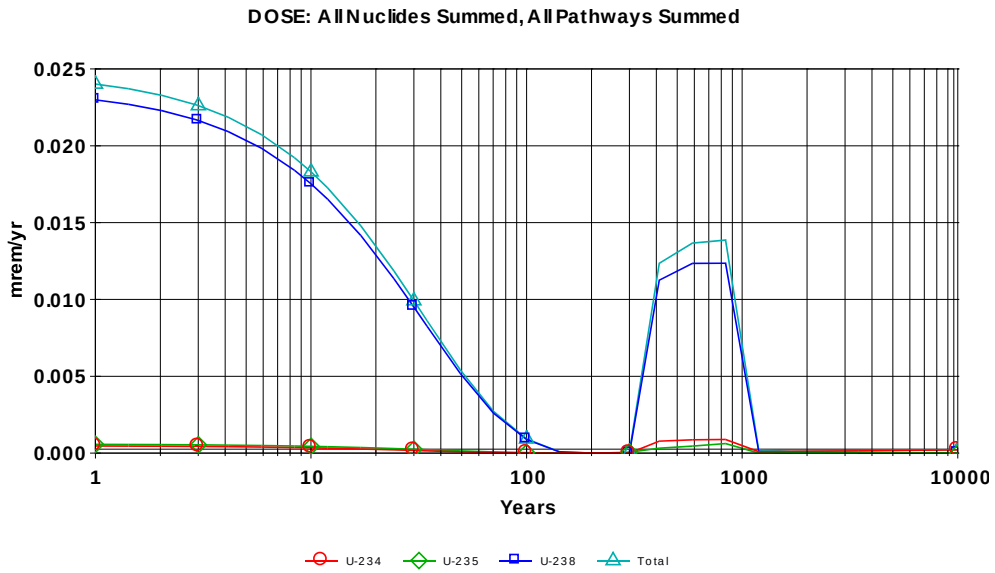


RCA Offsite (RESRAD-OFFSITE)

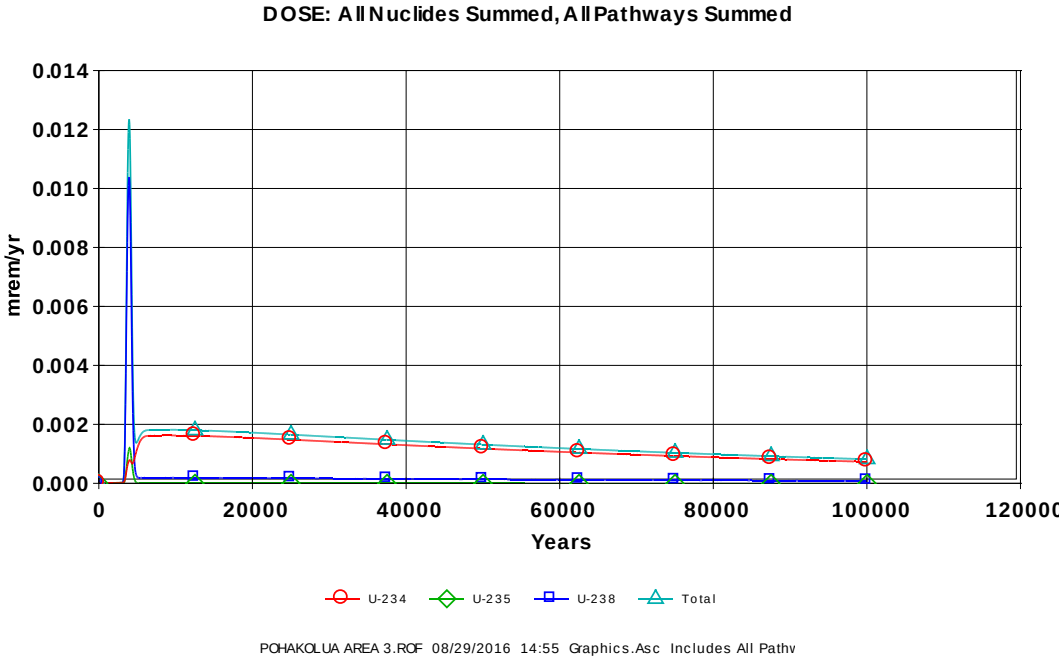


Davy Crockett Range Area 3

RCA Onsite (RESRAD)

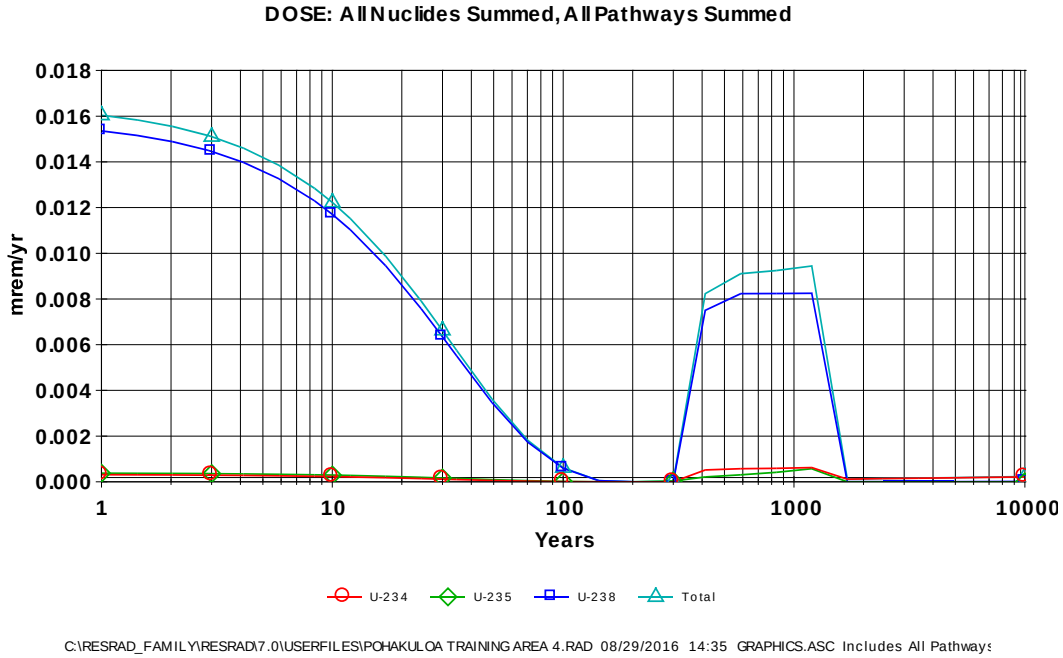


RCA Offsite (RESRAD-OFFSITE)

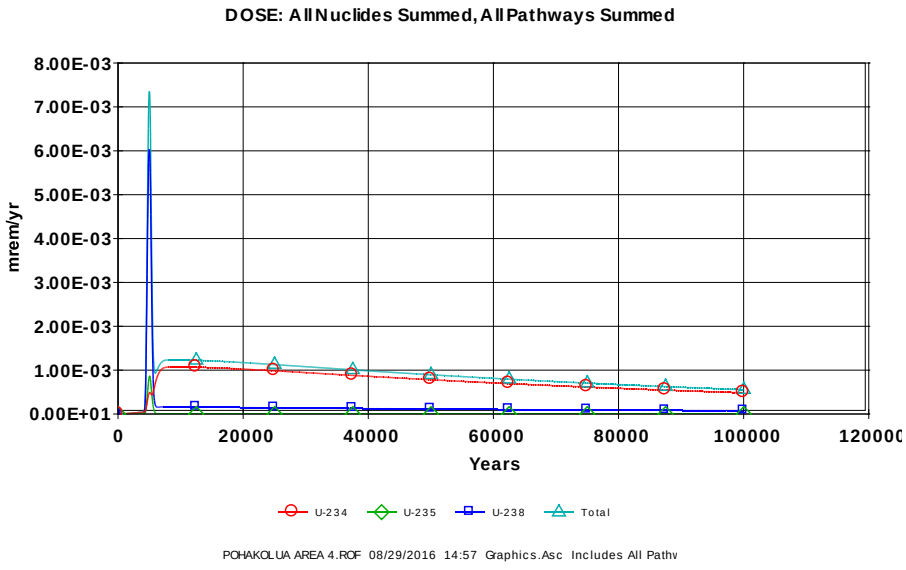


Davy Crockett Range Area 4

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)



Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	(Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$a_{\text{U-234}} = (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)}$$
$$a_{\text{U-235}} = (7.204 \times 10^{-3}) D_{\text{U-235}}$$
$$a_{\text{U-238}} = 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned}(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} &+ (2.16 \times 10^{-6}\text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &+ (3.36 \times 10^{-7}\text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &= 3.6 \times 10^{-7}\text{Ci g}^{-1}\end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

5.0 REFERENCES

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SITE-SPECIFIC ENVIRONMENTAL RADIATION MONITORING PLAN SCHOFIELD BARRACKS MILITARY RESERVATION, OAHU, HAWAII ANNEX 18

FOR MATERIALS LICENSE SUC-1593, DOCKET NO. 040-09083

March 2020

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
CD	Compact Disk
CFR	Code of Federal Regulations
CG	Commanding General
CoC	Chain of Custody
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DU	Depleted Uranium
ELAP	Environmental Laboratory Accreditation Program
ERM	Environmental Radiation Monitoring
ERMP	Environmental Radiation Monitoring Plan
HASL	Health and Safety Laboratory
ICP-MS	Inductively Coupled Plasma-Mass Spectroscopy
IMCOM	Installation Management Command
IDQTF	Intergovernmental Data Quality Task Force
kg	Kilogram
m^2	Square Meters
mSv/y	MilliSievert per Year
mrem/y	Millirem per Year
NRC	U.S. Nuclear Regulatory Commission
ORAP	Operational Range Assessment Program
PAERMP	Programmatic Approach for Preparation of Site-Specific Environmental Radiation Monitoring Plans
QA	Quality Assurance
QC	Quality Control
RCA	Radiation Control Area
RESRAD	Residual Radiation
RSO	Radiation Safety Officer
SBMR	Schofield Barracks Military Reservation
SDZ	Surface Danger Zone
SML	Source Material License
SOP	Standard Operating Procedure
TA	Training Area
TEDE	Total Effective Dose Equivalent
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UXO	Unexploded Ordnance

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1.0 INTRODUCTION

This Site-Specific Environmental Radiation Monitoring Plan (ERMP) has been developed to fulfill the U.S. Army's compliance with license conditions #18 and #19 of the U.S. Nuclear Regulatory Commission (NRC) source material license (SML) SUC-1593 for the possession of depleted uranium (DU) spotting rounds and fragments as a result of previous use at sites located at U.S. Army installations. This Site-Specific ERMP is an annex to the Programmatic Approach for Preparation of Site-Specific ERMPs (PAERMP) (U.S. Army 2020) and describes the additional details related to Schofield Barracks Military Reservation (SBMR), Oahu, Hawaii, in addition to those presented in the PAERMP. This Site-Specific ERMP supersedes the Site-Specific ERMP for SBMR, Oahu, Hawaii, Annex 18 (ML16265A232) (U.S. Army 2016).

1.1 PURPOSE

NRC issued SML SUC-1593 to the Commanding General (CG) of the U.S. Army Installation Management Command (IMCOM) authorizing the U.S. Army to possess DU related to historical training with the 1960s-era Davy Crockett weapons system at several installations nationwide. In order to comply with the conditions of the license, this Site-Specific ERMP has been developed to identify potential routes for DU transport and describe the monitoring approach to detect any off-installation migration of DU remaining from the use of the Davy Crockett weapons system at SBMR. The installation will retain the final version of this Site-Specific ERMP. This Site-Specific ERMP and its implementation is subject to NRC inspection. Table 1-1 summarizes the locations, media, and frequency of sampling described further in this Site-Specific ERMP.

Table 1-1. Selected ERM Sample Locations

Sample Location	Sample Media	Sample Frequency
Three co-located surface water and sediment samples downstream (**SWS-01, SWS-02, SWS-03**) from the Davy Crockett RCA, as shown in Figure 1-2 based on the rationale presented in Section 2.1	Surface water and sediment based on the programmatic rationale presented in the PAERMP and site-specific details presented in Section 2	Semiannually unless prevented by weather (e.g., regional flooding)

1.2 INSTALLATION BACKGROUND

SBMR is located in central Oahu, Hawaii, approximately 22 miles northwest of Honolulu (Figure 1-1). The installation's operational footprint encompasses 14,978 acres, including 109 operational ranges covering 12,801 acres. Two distinct and separate areas constitute SBMR, the Main Post (10,040 acres) and Schofield Barracks East Range (4,950 acres), which are separated by Wheeler Army Airfield and Wahiawa Reservoir. As the home of the 25th Infantry Division, SBMR's primary mission is to support the strategy of the Pacific theatre, including deployment and combat missions at a moment's notice.

The Main Post is bordered to the northwest by Mt. Kaala Natural Area Reserve and to the west by Waianae Kai Forest Reserve. The Lualualei Naval Reservation and Kunia Military Reservation lie southwest and southeast of the Main Post, respectively. The Main Post includes a non-operational cantonment area. Range types located on the Main Post consist of maneuver and training areas, live-fire ranges, and a Dudded Impact Area.

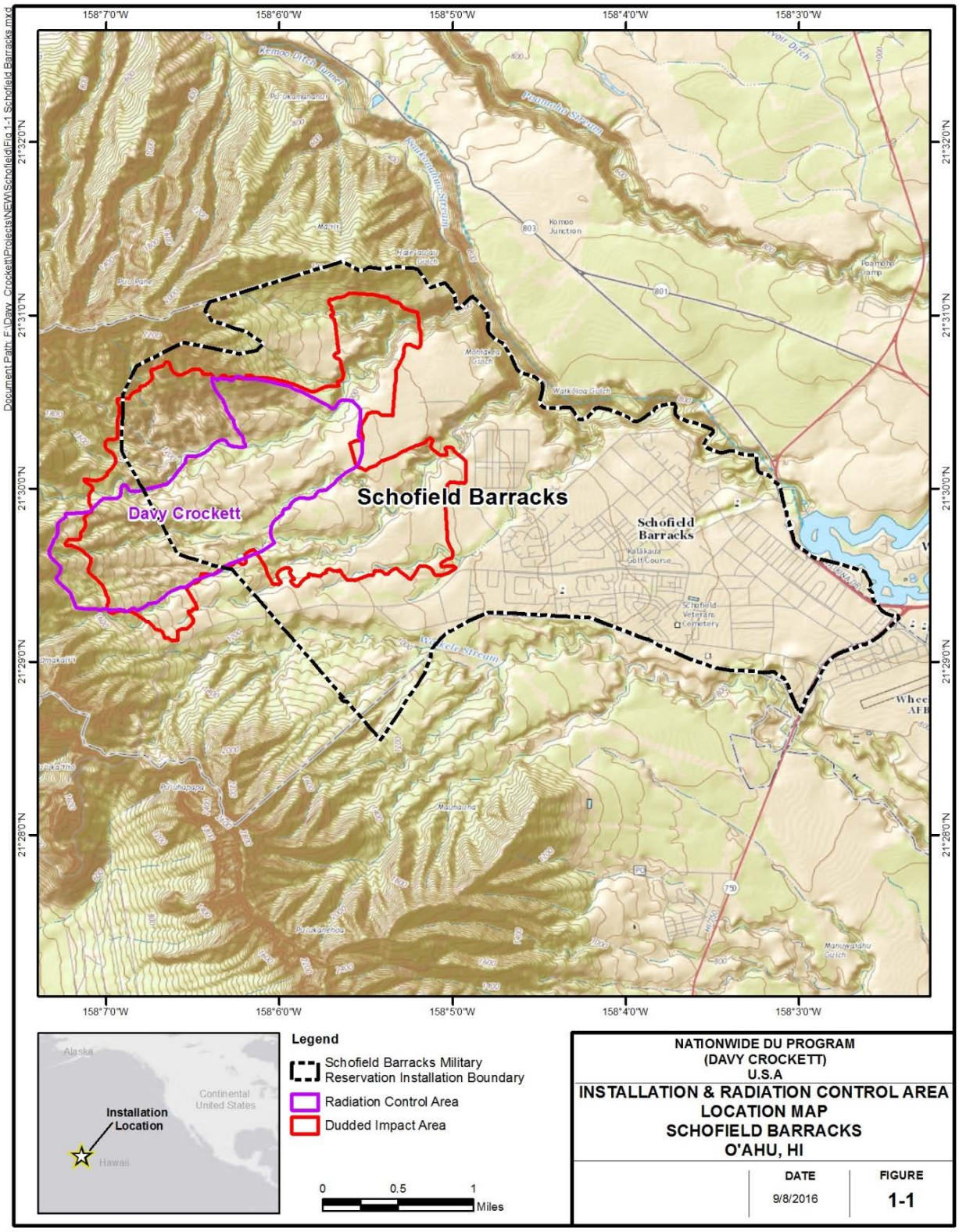

Figure 1-1. Installation and Radiation Control Area Location Map

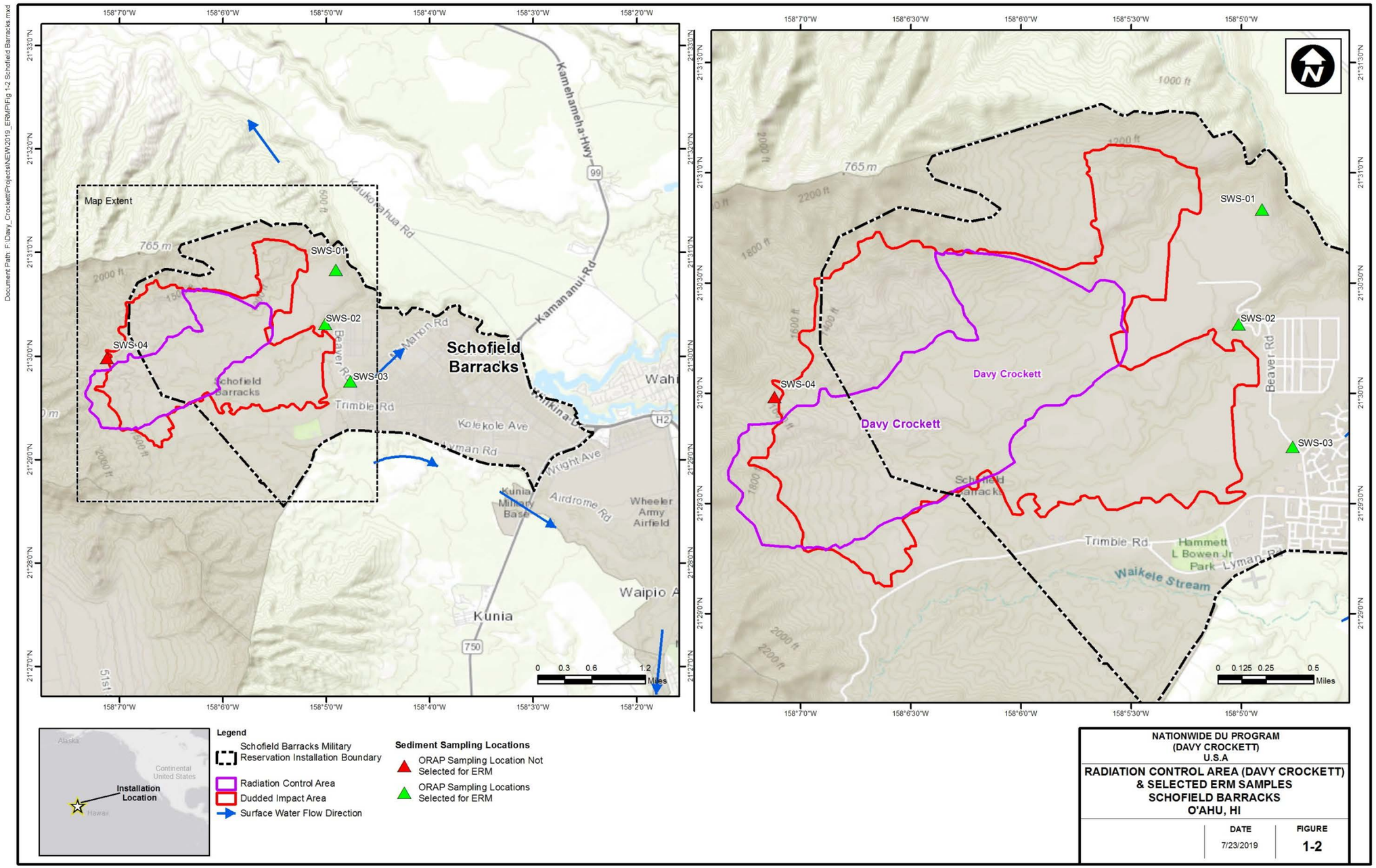

Figure 1-2. Radiation Control Area (Davy Crockett) and Selected ERM Sample Locations

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The East Range is primarily used for infantry training and maneuvers. Training activities include obstacle and confidence courses, jungle survival, patrolling operations, airborne operations, and limited battalion and company-level missions. No live-fire exercises are conducted at the East Range, and the range area consists entirely of maneuver and training areas. The adjoining U.S. Army Kawailoa Training Area lies on the northern boundary of the East Range.

SBMR was selected in 1908 as the base for Oahu's mobile defense troops due to its strategic central location between the Waianae Mountains and the Koolau Range. Following World War I, the Army formed a combat division at SBMR. This division was reorganized in 1941, forming the 24th and 25th (later renamed Tropic Lightning) Divisions. From 1961 to 1968, soldier training exercises at SBMR utilized M101 ammunition from the Davy Crockett Light Weapon M28 and Davy Crockett Heavy Weapon M29. This ammunition included a spotting round that contained a DU component. The Davy Crockett weapon systems were deactivated after 1968 at SBMR (EA 2012).

The Archives Search Report (ASR) (USACE 2007) confirmed the presence of the Davy Crockett Range based on visual evidence, consisting of range scrap and residue from the 20mm spotting and 279mm practice round. A launching piston also was located in the area where the range scrap was observed. The nearest normally occupied areas to the Davy Crockett Range or radiation control area (RCA) is 0.1 miles to the south.

1.3 HISTORICAL INFORMATION

The M101 spotting round contained approximately 6.7 ounces of DU and was a component of the 1960s-era Davy Crockett weapons system. Used for targeting accuracy, the M101 spotting rounds emitted white smoke upon impact. The rounds remained intact or mostly intact on or near the surface following impact and did not explode. Remnants of the tail assemblies may remain at each installation where the U.S. Army trained with the Davy Crockett weapons system from 1960 to 1968. These installations include Fort Benning, Fort Bragg, Fort Campbell, Fort Carson, Fort Gordon, Fort Hood, Fort Hunter Liggett, Fort Jackson, Fort Knox, Fort Polk, Fort Riley, Fort Sill, Fort Wainwright (includes Donnelly Training Area [TA]), Joint Base Lewis-McChord (Fort Lewis and Yakima TA), Joint Base McGuire-Dix-Lakehurst (Frankford Arsenal Range), Schofield Barracks Military Reservation, and Pohakuloa TA.

The U.S. Army does not know if any cleanup or retrieval of these rounds or remnants has occurred at the Davy Crockett Range located within SBMR; therefore, it is assumed that most, if not all, of the 140 kilograms (kg) of DU from the rounds fired into RCAs at Schofield Barracks and the Pohakuloa TA remains in the RCA.

1.4 PHYSICAL ENVIRONMENT

Surface water on SBMR consists of ephemeral streams, perennial streams, springs, wetlands, manmade tunnels, and portions of the Wahiawa reservoir. There are two primary watersheds that drain surface water from the installation: the Kaukonahua watershed to the north and the Waikele to the south. The Kaukonahua drains the majority of the installation and transports surface water across the installation to the west and then to the northwest while the Waikele watershed drains the southern extent of the Main Post, transporting water toward Wheeler Army Airfield in a mostly southern direction. Both watersheds are hemmed in on the eastern and western boundaries by the Koolau Range and the Waianae Range, respectfully. Streams flowing off of these mountain ranges come together on the Schofield Plateau, which encompasses the central area of SBMR, before being redirected toward the north or south.

The Main Post is primarily drained by Haleauau Gulch, Waikoloa Gulch, and Mohiakea Gulch in the Kaukonahua watershed and by Waikele stream in the Waikele watershed. Streams on the Main Post are ephemeral, flow eastward, and exit the installation on the eastern boundary. The three major streams within

the Kaukonahua watershed flow into Kaukonahua stream and follow a north-northwesterly direction into Kaiaka-Waialua Bay at Waialua, approximately 6.5 stream miles north of the installation boundary.

All surface water exiting the southern portion of the Main Post area from the Waikele watershed is via Waikele Stream, which is fed by Maunauna Gulch and three unnamed tributaries. Surface water across the Waikele watershed region flows east from the Waianae Range and converges into Waikele Stream, eventually turning south where it discharges into the West Loch of Pearl Harbor located approximately 10.5 stream miles from the installation boundary. Although Waikele stream's drainage area encompasses approximately 3,200 acres within SBMR, the lack of rainfall within the stream's regional headwaters coupled with the stream's undefined channel results in very little concentrated flow exiting the installation.

Groundwater within the SBMR region consists of the central Oahu groundwater flow system, which is the largest system on the island, receiving approximately 70 percent of the total island recharge. This groundwater system is bounded to the east and west by the Koolau and Waianae ranges and to the north and south by coastal sedimentary deposits.

Within the groundwater flow system, the overlapping Koolau Volcanics and Waianae Basalt form a multi-layered aquifer system that contains an intervening, semi-confining unit created by the clay-rich soil and saprolite at the top of the Waianae Volcanics. Groundwater flow in the volcanic aquifers is inward from the Koolau and Waianae ranges to the Schofield Plateau, where a groundwater divide directs the flow north and south toward the coasts. It is primarily controlled by precipitation and changes in topography.

Three primary aquifers comprise the Oahu groundwater flow system: the deeper Basal aquifer and the more surficial aquifers consisting of the Schofield high level water body, and the dike-impounded water body. In addition, groundwater occurs locally within perched aquifers above the Basal aquifer. The aquifers are recharged from both upgradient areas near the mountain crests and from vertical infiltration at the Schofield Plateau ground surface, often through several hundred feet of unsaturated, unweathered rock. However, due to the low permeability of the clay-rich soil and saprolite, which is thought to underlie the entire Schofield Plateau, vertical leakage from surface water/runoff is considered minimal. Recharge ranges from approximately 10 to 30 inches per year, occurring primarily in the mountains, and is highly dependent upon precipitation and topography. Evapotranspiration rates are also a factor and are relatively high (ranging from 40 to 60 inches annually) (EA 2012).

1.5 EVALUATION OF POTENTIAL SOURCE-RECEPTOR INTERACTIONS

The transport of DU can be potentially completed along the identified pathways to human and/or ecological receptors. Specific details regarding the potential receptors for the Davy Crockett Range at SBMR are as follows:

- ***Sensitive Environments***—SBMR is located in an ecologically diverse area whose habitats support rare, threatened, or endangered species of plants and animals. There are more than 10 rare and/or threatened species that inhabit the areas proximal to the stream pathways. The Pearl Harbor National Wildlife Refuge is also located within the West Loch of Pearl Harbor, less than 7 miles from the installation.
- ***Habitat***—The habitats within and surrounding SBMR include freshwater wetlands and coastal marshes, perennial streams, subtropical forests, shrublands, and grasslands. In addition, artificial habitat types on and around SBMR include arable lands and plantations.
- ***Ecological Receptors***—The areas surrounding the installation include a number of rare, threatened, and endangered species. Many of these species are found in isolated areas dependent on elevation, topography, and prevailing ecological conditions upgradient of the installation. The Hawaiian coot (*Fulicia alai*), Hawaiian moorhen (*Gallinula chloropus*

sandvicensis), Hawaiian stilt (*Himantopus mexicanus knudseni*), and Hawaiian duck (*Anas wyvilliana*), and the plant species akoko (*Chamaesyce rockii*) and Ewe hinahina (*Achyranthes splendens*) have been identified as potential ecological receptors. Additional receptors include the Oahu damselfly (*Megalagrion oahuense*), blackline megalagrion damselfly (*M. nigrohamatum nigrolineatum*), and the dragonfly Anax strennus (no common name) found in the North Fork of Kaukonahua Stream. The Oahu elepaio (*Chasiempis sandwichensis ibidis*) is found downstream from Wahiawa Reservoir on the North Fork of Kaukonahua Stream.

- ***Groundwater Use***—There are six irrigation wells downgradient and to the north of the installation boundary and an additional three downgradient from and to the south. These wells support a number of human communities, such as Wahiawa, Mililani Town, Wheeler Army Airfield, and Waipio Acres.

Potential human receptors include those within SBMR and the nearby communities relying on potential public and private wells downgradient from the RCA for potable water. Ecological receptors include sensitive environments and the rare and/or threatened species in the areas surrounding the installation.

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2.0 ERMP SAMPLE DESIGN

The PAERMP documented the conditions (i.e., "if-then" statements) for the sampling of each environmental medium to be used during the development of the Site-Specific ERMPs, and only environmental media recommended for sampling in the PAERMP are presented in the sections below. Per the PAERMP, no sampling will occur within the RCA or in the unexploded ordnance (UXO) areas (also referred to as Dudded Impact Areas). In addition, background/reference sampling is not required because the determination of DU presence will be based on an examination of the isotopic uranium ratios. The sampling approach and rationale for each medium for the RCA at SBMR are discussed in the following sections.

2.1 SEDIMENT

Since the prevailing characterization of surface water at SBMR is ephemeral in nature, most streams and tributaries within SBMR flow only during storm events; therefore, sampling is restricted to sediment collection only. The sediment sampling approach will involve the semiannual collection of sediment samples from a location downstream from the RCA in the SBMR (Figure 1-2). The sediment sampling location at SBMR was selected based on the surface water hydrology and potential for DU migration and is located as follows:

- ***SWS-01***—The selected sampling point is located on Haleauau Gulch, approximately 1,700 feet from the installation boundary.
- ***SWS-02***—The selected sampling point is located on Mohiakea Gulch, approximately 3,000 feet from the installation boundary.
- ***SWS-03***—The selected sampling point is located on Waikoloa Gulch, approximately 1,000 feet from the installation boundary. Waikoloa Gulch drains the RCA and firing points along the southern edge of the Dudded Impact Area.

Sediment samples will be analyzed for total/isotopic uranium using U.S. Department of Energy (DOE) Health and Safety Laboratory (HASL) method 300 (alpha spectrometry). Further details of analytical procedures and quality assurance/quality control (QA/QC) information are presented in Annex 19. When analytical sampling results from locations outside the RCA indicate that the uranium-238 (U-238)/uranium-234 (U-234) activity ratio exceeds 3.0, the U.S. Army will notify NRC within 30 days and collect additional sediment samples within 30 days of the notification to NRC, unless prohibited by the absence of the sampling media. The analytical samples displaying an activity ratio exceeding 3.0 will be reanalyzed using inductively coupled plasma-mass spectroscopy (ICP-MS) for their U-234, uranium-235 (U-235), and U-238 content to calculate the U-235 weight percentage specified in 10 Code of Federal Regulations (CFR) § 110.2 (Definitions) and then to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235).

The selected sampling locations were sampled during the Operational Range Assessment Program (ORAP) Phase II assessment in 2013 and analyzed for uranium in surface water and sediment (EA 2015). The range of U-238/U-234 activity ratios from the sampling events is presented in Tables 2-1 and 2-2.

Table 2-1. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
SWS-01	2	ND
SWS-04 (reference)	1	ND

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

ND – Indicates that one or more isotopes were not detected; therefore, the calculation was not performed.

Table 2-2. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2013 ORAP Phase II Assessment

Sample Location	Number of Samples	U-238/U-234 Ratio Range* (unitless)
SWS-01	6	0.71-1.04
SWS-02	5	0.819-1.14
SWS-03	5	0.74-1.04
SWS-04 (reference)	4	0.715-1.327

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

In accordance with the Site-Specific ERMP for SBMR, Oahu, Hawaii, Annex 18 (ML16265A232) (U.S. Army 2016), the Army conducted quarterly sediment sampling at the selected sampling locations, SWS-01, SWS-02, and SWS-03, in 2017 and 2018. In addition, surface water samples were collected when possible. The concentrations of total and isotopic uranium in surface water and sediment from the environmental radiation monitoring (ERM) sampling events at SBMR are presented in the Radiation Monitoring Report, Summary of Results for Summer, Fall, and Winter 2017 Sampling Events (ML18136A796) (U.S. Army 2018) and Radiation Monitoring Report, Summary of Results for 2018 Sampling Events (ML19115A040) (U.S. Army 2019). The U-238/U-234 activity ratios from the ERM sampling events are presented in Tables 2-3 and 2-4.

Table 2-3. U-238/U-234 Activity Ratios for Surface Water Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-02	9/7/2018	0.91 +/- 0.35
SWS-03	9/7/2018	0.89 +/- 0.26
SWS-01	12/11/2018	1.2 +/- 0.3
SWS-02	12/11/2018	0.86 +/- 0.29
SWS-03	12/11/2018	1.0 +/- 0.3

* The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural, depleted, or enriched uranium. U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016).

+/- – Laboratory uncertainties are specified with two standard deviations (95 percent confidence level).

Table 2-4. U-238/U-234 Activity Ratios for Sediment Samples Collected During the 2017 and 2018 ERM Sampling Events

Sample Location	Date	U-238/U-234 Ratio* (unitless)
SWS-01	6/15/2017	0.87 +/- 0.34
SWS-02	6/15/2017	1.0 +/- 0.5
SWS-03	6/15/2017	0.88 +/- 0.33
SWS-01	9/7/2017	0.83 +/- 0.23
SWS-02	9/7/2017	1.0 +/- 0.3
SWS-03	9/7/2017	0.80 +/- 0.32
SWS-01	11/29/2017	1.1 +/- 0.3
SWS-02	11/29/2017	0.87 +/- 0.33
SWS-03	11/29/2017	0.79 +/- 0.24
SWS-01	2/21/2018	0.84 +/- 0.21
SWS-02	2/21/2018	0.87 +/- 0.33
SWS-03	2/21/2018	0.89 +/- 0.25
SWS-01	6/18/2018	0.84 +/- 0.21
SWS-02	6/18/2018	0.72 +/- 0.31
SWS-03	6/18/2018	0.86 +/- 0.24
SWS-01	9/7/2018	1.1 +/- 0.4

U-238/U-234 activity ratios of 3.0 or less are representative of natural uranium, whereas higher ratios are potentially indicative of DU (NRC 2016). As shown in Tables 2-1 through 2-4, U-238/U-234 activity ratios that could be potentially indicative of DU have not been observed in surface water and sediment at SBMR.

2.2 GROUNDWATER

Groundwater sampling was not conducted during the ORAP Phase II assessment. Since the permeability of soil is considered to be low and vertical leakage from surface water/runoff is considered minimal, any DU potentially present in surface water that could impact groundwater would likely have been detected through sediment sampling. For this reason and additional rationale included in the PAERMP (U.S. Army 2020), groundwater sampling is not planned for SBMR.

2.3 SOIL

If an area of soil greater than 25 square meters (m^2) eroded from an RCA is discovered during routine operations and maintenance activities, the U.S. Army will sample that deposit semiannually with one sample taken per 25 m^2 unless the soil erosion is located in a UXO area. The collection of environmental radiation samples in UXO areas generally will not occur. Exceptions will occur only with documented consultation among the License Radiation Safety Officer (RSO), installation safety personnel, and range control personnel, who will advise the Installation Commander (i.e., they will prepare a formal risk assessment in accordance with U.S. Army [2014]). The Installation Commander will then decide whether to allow the collection. Otherwise, SBMR does not meet any other criteria that would require soil sampling in accordance with the PAERMP (U.S. Army 2020).

Prior to mobilization, field sampling personnel will contact Range Control, the Installation RSO, or designee to determine if erosional areas within the RCA have been identified and, if so, sampled in accordance with requirements in Section 3.0 and Annex 19.

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3.0 ERMP METHODOLOGY

The sampling and laboratory analysis procedures to be utilized during the ERM are described below. These procedures provide additional details and required elements to support the Site-Specific ERMP and must be utilized in conjunction with the standard operating procedures (SOPs) during execution of ERM activities. This Site-Specific ERMP is to be used in conjunction with Annex 19, which addresses programmatic requirements associated with ERM sampling, such as chain-of-custody (CoC), packaging for shipment, shipping, collecting field QC samples (e.g., field duplicate samples), and documenting potential variances from sampling procedures. Annex 19 has been prepared in accordance with guidance from the Uniform Federal Policy for Quality Assurance Project Plan (UFP-QAPP) Optimized Worksheets (IDQTF 2012). All entry to SBMR will be coordinated with the SBMR Safety Office and Range Control prior to mobilizing for fieldwork.

3.1 LABORATORY ANALYSIS

Only a laboratory that the U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP) has accredited for uranium analysis using both alpha spectrometry and ICP-MS methods will perform radiochemical analyses for the purposes of NRC license compliance. The U-238 to U-234 activity ratio and the weight percent U-235 are used to determine whether a given sample is indicative of natural uranium or DU. The laboratory will use alpha spectrometry to analyze samples for U-234 and U-238 activities in order to comply with license condition #17 in NRC SML SUC-1593. All samples with U-238/U-234 activity ratios exceeding 3.0 will be reanalyzed using ICP-MS for their U-234, U-235, and U-238 content to identify samples with DU content (NRC 2016). The ICP-MS results for U-234, U-235, and U-238 are summed to calculate a total mass of uranium present, which will be used to calculate the weight percentage of U-235 mass to determine if the sample results are indicative of totally natural uranium (at or about 0.711 weight percent U-235) or DU mixed with natural uranium (obviously less than 0.711 weight percent U-235). Additional details about the sampling and analysis to support this Site-Specific ERMP are included in Annex 19.

3.2 SURFACE WATER SAMPLING

No surface water samples will be collected due to the ephemeral nature of surface water at SBMR.

3.3 SEDIMENT SAMPLING

Sediment samples will be collected from the drainage area using a clean, disposable plastic scoop. Sampling locations within the stream beds should be selected where the surface water flow is low and/or deposition is most likely, such as bends in the creek as it changes direction. The sediment sampling procedure is as follows:

1. The individual performing the sampling will don clean gloves and prepare a disposable tray or sealable plastic bag and a plastic scoop.
2. Use a disposable scoop to remove the loose upper sediment uniformly from the sample location. Do not exceed 3 centimeters in depth into the sediment. Collect a sufficient quantity of sediment for QA/QC.
3. Place sediment into a disposable tray or sealable plastic bag (e.g., Ziploc®).
4. Remove rocks, large pebbles, large twigs, leaves, or other debris.
5. Remove excess water from the sediment. This may require allowing the sample to settle.
6. Thoroughly mix (homogenize) the sediment within the disposable tray or bag.

7. Fill the appropriate sample containers.
8. Mark the sample location with a stake and log its coordinates using a differential global positioning system (DGPS) unit.
9. Collect digital photographs and document data in the field logbook.

Additional details of the sediment sampling and the field procedures are provided in Annex 19. Once samples are collected, the samples and all QA/QC samples will be shipped to the laboratory for analysis. Sample handling (i.e., labeling, packaging, and shipping) and CoC procedures will follow those detailed in Annex 19.

4.0 RESRAD CALCULATIONS

This section documents the dose assessment results for a hypothetical residential farmer receptor located on each RCA, as applicable, and for the same receptor scenario located at the nearest normally occupied area, respectively. The dose assessments were completed to comply with license condition #19 of NRC SML SUC-1593.

The dose assessments were conducted using the Residual Radiation (RESRAD) 7.2 (Yu et al. 2016a) and RESRAD-OFFSITE 3.2 (Yu et al. 2016b) default residential farmer scenario pathways and parameters with the following exceptions:

- Nuclide-specific soil concentrations for U-238, U-235, and U-234 were calculated for each RCA by multiplying the entire mass of DU listed on the license for the installation (140 kg for Schofield Barracks and Pohakuloa TA) by the nuclide-specific mass abundance, the nuclide specific activity, and appropriate conversion factors to obtain a total activity in picocuries (Table 4-1). That total activity was then assumed to be distributed homogenously in the top 6 inches (15 cm) of soil located within the area of the RCA.

Table 4-1. Specific Activity and Mass Abundance Values

Nuclide	Specific Activity Ci/g	Mass Abundance[b] %
U-234	6.22×10^{-3}	3.56×10^{-4}
U-235	2.16×10^{-6}	0.0938
U-238	3.36×10^{-7}	99.9058
Depleted uranium[a]	3.6×10^{-7}	100

[a] 10 CFR 20, Appendix B, Footnote 3.
[b] Mass abundance calculations provided in Attachment 1.

- Non-default site-specific parameters applicable to both RESRAD and RESRAD-OFFSITE are listed in Table 4-2.
- Non-default site-specific parameters applicable only to RESRAD-OFFSITE are listed in Table 4-3.
- Groundwater flow was conservatively set in the direction of the offsite dwelling.

4.1 RESRAD INPUTS

Table 4-2. Non-Default RESRAD/RESRAD-OFFSITE Input Parameters for Schofield Barracks RCA

Parameter		Default Value	SBMR Davy Crockett Range	Justification or Source
Internal dose library		DCFPAK 3.02	FGR 11 & 12	Conservative dose coefficients for site contaminants
Contaminated Zone				
Soil concentrations (pCi/g)	U-234	N/A	5.01×10^{-3}	Site-specific calculation based on the DU mass listed in the NRC SML (NRC 2016). = DU mass × nuclide specific mass abundance* × nuclide specific activity* / (CZ area × CZ depth × CZ density)
	U-235	N/A	4.58×10^{-4}	
	U-238	N/A	0.08	
Area of contaminated zone (m^2)		10,000	2,750,000	RCA area
Depth of contaminated zone (m)		2	0.15	NRC SML SUC-1593, Item 11, Attachment 5
Fraction of contamination that is submerged		0	0	Depth to groundwater is generally 600 ft bgs
Length parallel to aquifer flow (m)		100	1000	Groundwater flows north/south across RCA
Contaminated zone total porosity		0.4	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt
Contaminated zone hydraulic conductivity (m/y)		10	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Contaminated zone b parameter		5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Average annual wind speed (m/s)		2.0	5.0	**www.usa.com for Schofield Barracks, HI**
Precipitation rate (annual rainfall) (m/y)		1.0	0.9	**www.usa.com for Schofield Barracks, HI**
Saturated Zone				
Saturated zone total porosity		0.4	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt
Saturated zone effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Saturated zone hydraulic conductivity (m/y)		100	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Saturated zone b parameter		5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Unsaturated Zone				
Unsaturated zone 1, thickness (m)		4.0	180	Depth to groundwater is generally 600 ft bgs
Unsaturated zone 1, total porosity		0.4	0.45	RESRAD Manual Table E.8 (DOE 2001) for Silt
Unsaturated zone 1, effective porosity		0.2	0.2	RESRAD Manual Table E-8 (DOE 2001) for Silt
Unsaturated zone 1, soil-specific b parameter		5.3	10.4	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay
Unsaturated zone 1, hydraulic conductivity (m/y)		10	32.6	RESRAD Manual Table E.2 (DOE 2001) for Silty Clay

* See Table 1.

Table 4-3. Non-Default RESRAD-OFFSITE Input Parameters for Schofield Barracks RCA

RCA Layout Parameter	SBMR Davy Crockett Range			
Distance to nearest normally occupied area (m)	800			
Bearing of X axis (degrees)	135 (northeast)			
X dimension of Primary Contamination (m)	1,000			
Y dimension of Primary Contamination (m)	2,750			
Location	X Coordinate (m)		Y Coordinate (m)	
	Smaller	Larger	Smaller	Larger
Fruit, grain, non-leafy vegetables plot	500	531.25	3,650	3,682
Leafy vegetables plot	500	531.25	3,684	3,716
Pasture, silage growing area	500	600	3,866	3,966
Grain fields	500	600	3,716	3,816
Dwelling site	500	531.25	3,550	3,582
Surface-water body	500	800	3,966	4,266
Primary Contamination Parameter				
Length parallel to aquifer flow (m)[a]	141			
Atmospheric Transport Parameter				
Meteorological STAR file[b]	CA_SAN_DIEGO.str			
Groundwater Transport Parameter				
Distance to well (parallel to aquifer flow) (m)	800			
Distance to surface water body (SWB) (parallel to aquifer flow) (m)	1216			
Distance to well (perpendicular to aquifer flow) (m)	0			
Distance to right edge of SWB (perpendicular to aquifer flow) (m)	-150			
Distance to left edge of SWB (perpendicular to aquifer flow) (m)	150			
Anticlockwise angle from x axis to direction of aquifer flow (degrees)	315			

[a] Conservative value selected to maximize groundwater concentration and ensure that volumetric groundwater flow rate under the Contaminated Zone (CZ) exceeds or meets the recharge volumetric rate through the CZ.

[b] RESRAD Offsite has no meteorological STAR files for Alaska or Hawaii. The selected STAR file is based on nearest available location. The inhalation pathway dose is insignificant to external and groundwater dose pathways.

4.2 RESULTS

Table 4-4 presents the dose assessment results. Figure 4-1 presents graphs of the dose assessment results over the evaluation period. The calculated site-specific all pathway dose for the RCA evaluated at SBMR does not exceed 1.0×10^{-2} milliSievert per year (mSv/y) (1.0 millirem per year [mrem/y]) total effective dose equivalent (TEDE) and meets license condition #19 of NRC SML SUC-1593.

Table 4-4. RESRAD-Calculated Maximum Annual Doses for Resident Farmer Scenario

RCA	RCA Onsite[a] (RESRAD)	RCA Offsite[b] (RESRAD-OFFSITE)
	Maximum Annual Dose (mrem/y)	
Schofield Barracks	0.017	2.6×10^{-3}

[a] The onsite residential farmer receptor resides on the RCA.

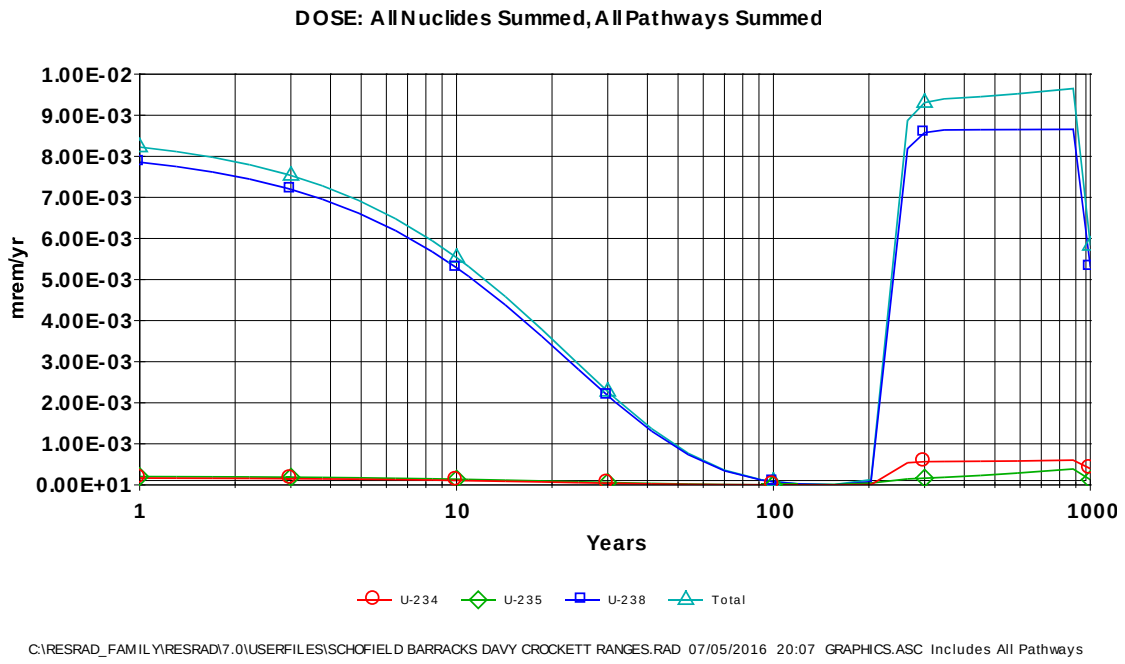
[b] The offsite residential farmer receptor resides off of the RCA, but within the installation, at the nearest normally occupied area.

RESRAD and RESRAD-OFFSITE output reports for each RCA are provided on the compact disk (CD).

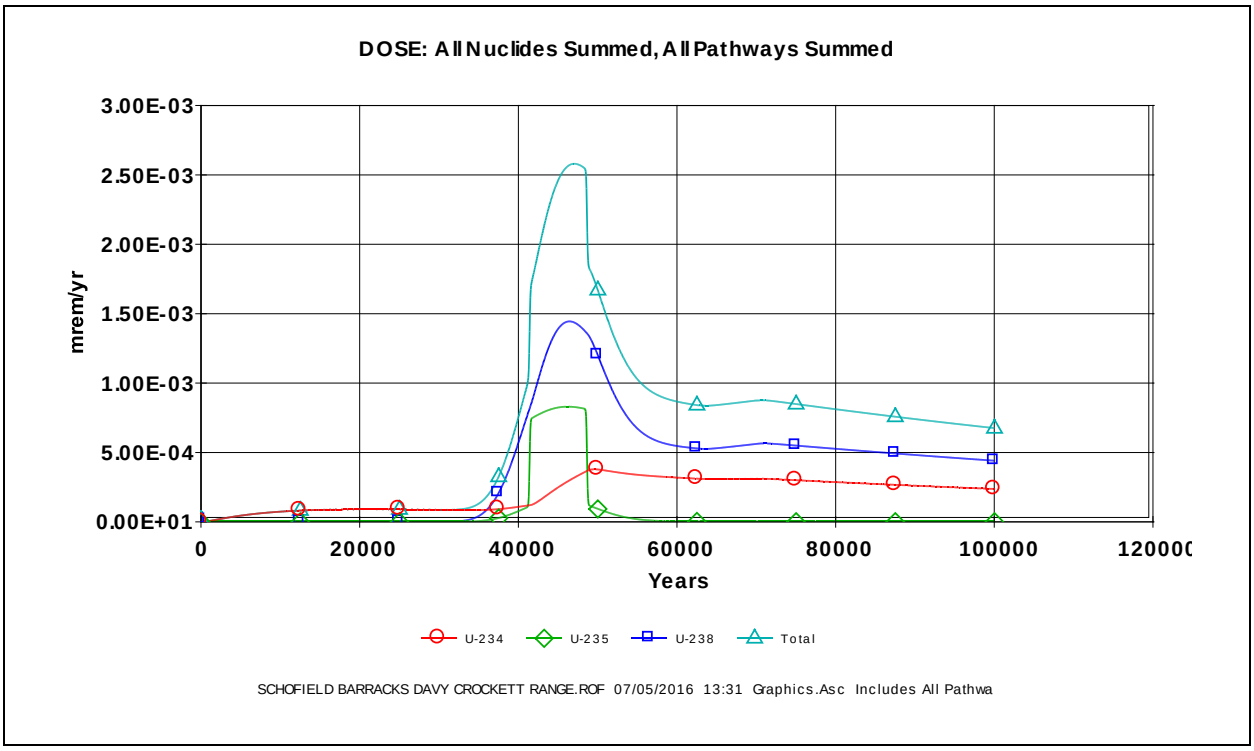
Figure 4-1. Residential Farmer Receptor Dose Graphs

Schofield Barracks Davy Crockett Range

RCA Onsite (RESRAD)



RCA Offsite (RESRAD-OFFSITE)


DOSE: All Nuclides Summed, All Pathways Summed
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+01
mrem/yr
0
20000
40000
60000
80000
100000
120000
Years
U-234
U-235
U-238
Total
SCHOFIELD BARRACKS DAVY CROCKETT RANGE.ROF 07/05/2016 13:31 Graphics.Asc Includes All Pathwa

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Attachment 1

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Analysis of NRC's Default Value for Depleted Uranium Specific Activity

Each of the values of the relative mass abundances for the naturally occurring uranium isotopes in the legacy Davy Crockett depleted uranium on Army ranges helps determine the source terms for RESRAD calculations, the performance of which is a license condition. This note shows how I estimated them using the NRC default value for the specific activity of depleted uranium.

The third footnote to the tables in Appendix B of Title 10, Code of Federal Regulations (CFR), Part 20, "Standards for Protection Against Radiation," says, "The specific activity for ... mixtures of U-238, U-235, and U-234, if not known, shall be: SA = 3.6E-7 curies/gram U for U-depleted." However, 10 CFR 20 does not describe how the NRC arrived at that value and I have not been able to learn this from NRC sources.

In general, the following equation provides the specific activity for a mixture of the three naturally occurring isotopes of uranium[1]:

$$S = \sum_i S_i \, a_i$$

S is the specific activity of the mixture of naturally occurring uranium isotopes, S_i is the specific activity for uranium isotope i, a_i is the relative molar mass abundance for uranium isotope i in the depleted uranium, and i denotes the uranium isotopes uranium-234 (^{234}U), ^{235}U and ^{238}U.

Rather than looking up each S_i in a table, I calculated them from fundamental values to maximize accuracy. By definition, the specific activity for a particular isotope S_i is the activity A_i per mass m_i for the isotope i. Also, by definition:

$$A_i = \lambda_i N_i$$

λ_i is the decay constant and N_i is the number of atoms of uranium isotope i in the sample with mass m_i. Thus,

$$S_i = \frac{\lambda_i N_i}{m_i}$$

λ_i is related to the half-life $t_{½i}$ as follows:

$$\lambda_i = \frac{\ln 2}{t_{½i}}$$

If N_i is set to Avogadro's number ($N = 6.02 \times 10^{23}$),[2] then, by definition, m_i is the mass of a mole of isotope i, given by M_i, which is the atomic weight of isotope i with assigned units of grams. So,

$$S_i = \frac{N \ln 2}{t_{½i} M_i}$$

[1] Although contaminants, including ^{236}U, are possible, even likely, at levels less than parts per million, I am not including contaminants in these calculations nor in the RESRAD calculations because of their negligible impact on the results.

[2] In performing the calculations, I used all available significant digits in a spreadsheet. This note generally displays only two or three significant digits in the equations. Minor discrepancies in calculated results are due to round-off.

Values of the relative molar mass abundances, the half-lives, and the atomic weights for the naturally occurring uranium isotopes are available on a chart of the nuclides.[3] The following table contains data used in calculations below:

Table — Isotopic Properties

Isotope	Natural Relative Molar Mass Abundance	Half-life (s)	Molar Mass (g)	Specific Activity[4] (Bq g^{-1})	Specific Activity[4] (Ci g^{-1})
^{234}U	0.000054	7.75×10^{12}	234.04	2.30×10^{8}	6.22×10^{-3}
^{235}U	0.007204	2.22×10^{16}	235.04	7.99×10^{4}	2.16×10^{-6}
^{238}U	0.992742	1.41×10^{17}	238.05	1.24×10^{4}	3.36×10^{-7}

By definition:

$$1 = a_{\text{U-234}} + a_{\text{U-235}} + a_{\text{U-238}}$$

A second equation involves the ratio of $a_{\text{U-234}}$ to $a_{\text{U-235}}$ in depleted uranium. If $a_{0,\text{U-234}}$ is the natural relative mass abundance for ^{234}U and $a_{0,\text{U-235}}$ similarly for ^{235}U, then

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-234}}$$
$$a_{\text{U-235}} = a_{0,\text{U-235}} D_{\text{U-235}}$$

$D_{\text{U-234}}$ is the depletion of ^{234}U in depleted uranium and $D_{\text{U-235}}$ similarly for ^{235}U, with

$$0 \text{ (complete depletion)} \leq D_i \leq 1 \text{ (no depletion)}$$

Kolafa[5] estimated the depletion of ^{234}U relative to the depletion of ^{235}U as follows:

$$D_{\text{U-234}} = (1 - 4\varepsilon)^n$$
$$D_{\text{U-235}} = (1 - 3\varepsilon)^n$$

ε is the single stage enrichment efficiency per the difference of the uranium isotope atomic mass number from the atomic mass number of ^{238}U and is much less than one. n is the number of enrichment stages.

For large n:

$$D_{\text{U-234}} \to e^{-4n\varepsilon}$$
$$D_{\text{U-235}} \to e^{-3n\varepsilon}$$

Eliminate the product $n\varepsilon$ by taking the logarithm of both equations:

$$\ln D_{\text{U-234}} = -4n\varepsilon$$
$$\ln D_{\text{U-235}} = -3n\varepsilon$$

[3] For example, see http://atom.kaeri.re.kr/nuchart/.
[4] 1 curie (Ci) = 3.7 × 10^{10} becquerels (Bq)
[5] http://www.ratical.org/radiation//vzajic/u234.html

So,

$$n\varepsilon = -\frac{1}{3}\ln D_{\text{U-235}}$$

Substituting for $n\varepsilon$

$$\ln D_{\text{U-234}} = \frac{4}{3}\ln D_{\text{U-235}}$$

Finally, exponentiating both sides of the equation,

$$D_{\text{U-234}} = D_{\text{U-235}}^{(4/3)}$$

So,

$$a_{\text{U-234}} = a_{0,\text{U-234}} D_{\text{U-235}}^{(4/3)}$$

Thus,

$$\begin{aligned} a_{\text{U-234}} &= (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} \\ a_{\text{U-235}} &= (7.204 \times 10^{-3}) D_{\text{U-235}} \\ a_{\text{U-238}} &= 1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}} \end{aligned}$$

The NRC provides in 10 CFR 20:

$$S = 3.6 \times 10^{-7}\ \text{Ci g}^{-1}$$

Returning to the first equation above, then

$$\begin{aligned} &(6.22 \times 10^{-3}\ \text{Ci g}^{-1})(5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} + (2.16 \times 10^{-6}\ \text{Ci g}^{-1})(7.204 \times 10^{-3}) D_{\text{U-235}} \\ &\quad + (3.36 \times 10^{-7}\ \text{Ci g}^{-1}) \left[1 - (5.4 \times 10^{-5}) D_{\text{U-235}}^{(4/3)} - (7.204 \times 10^{-3}) D_{\text{U-235}}\right] \\ &\quad = 3.6 \times 10^{-7}\ \text{Ci g}^{-1} \end{aligned}$$

Dividing by 10^{-7} Ci g^{-1} and collecting terms,

$$3.36 D_{\text{U-235}}^{(4/3)} + 0.131 D_{\text{U-235}} - 0.239 = 0$$

Solving, $D_{\text{U-235}} = 0.13$, and[6]

$$\boxed{\begin{aligned} a_{\text{U-234}} &= 0.00000356 \\ a_{\text{U-235}} &= 0.00093806 \\ a_{\text{U-238}} &= 0.99905838 \end{aligned}}$$

[6] The values for ^{234}U and ^{235}U actually contain only one or two significant digits. I show more digits because I will use them in RESRAD calculations. Properly, the results should read $a_{\text{U-234}} = 0.000004$, $a_{\text{U-235}} = 0.0009$, and $a_{\text{U-238}} = 0.9991$. For comparison, typical isotopic abundances in depleted uranium according to the Department of Energy are $a_{\text{U-234}} = 0.000007$, $a_{\text{U-235}} = 0.0020$, and $a_{\text{U-238}} = 0.9980$ (DOE-STD-1136-2009), which corresponds to a specific activity of $S = 3.8 \times 10^{-7}$ Ci g^{-1}. I note that the derived DOE value for $D_{\text{U-234}}$ is 0.13, which is inconsistent with Kolafa's estimate calculated from the derived DOE value for $D_{\text{U-235}}$: $D_{\text{U-235}}^{(4/3)} = (0.28)^{(4/3)} = 0.18$.

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